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DEVELOPMENT AND IMPLEMENTATION OF AIR MODULE ALGORITHMS FOR THE FUTURE THEATER LEVEL MODEL

by

Wang, Hua-Chung
Lieutenant, Taiwan, R.O.C. Navy
B.S., Chinese Naval Academy, 1986

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
NAVAL POSTGRADUATE SCHOOL

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This thesis designs, develops, and tests three models which comprise the dynamic air route selection package for use in the Future Theater-Level Model (FTLM). Model I computes the portion of each square air grid covered by a selected characteristic radius of each ground unit. Model II uses Dynamic Programming and priority queue techniques to select ingress (and separate) egress routes from flight group air rendezvous points to a designated air grid which may be a target, reconnaissance area, or orbit location. Model III simultaneously selects a target from several candidates, selects a route and determines the implications of various escort aircraft levels in an optimal fashion, based on the measure of effectiveness (MOE) of minimizing the combined value of three factors (tactical difficulty, travel distance/time, and target priority). Comparison of different ground situations and weight sets associated with these three factors are presented to illustrate the flexibility and use of these models.

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The reader is cautioned that computer programs deverloped in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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TABLE OF CONTENTS

I. INTRODUCTION 1

II. BACKROUND 3

A. GROUND NETWORK AND UNITS 4

B. AIR NETWORK AND UNITS 5

III. AIR GRID COVERAGE MODEL (MODEL I) 7

A. INTRODUCTION 7

B. MODEL ALGORITHM 8

C. MODEL DEMONSTRATION/VERIFICATION 13

1. VERIFICATION 13

2. DEMONSTRATION 17

IV. AIR ROUTE SELECTION MODEL (MODEL II) 19

A. INTRODUCTION 19

B. MODEL ALGORITHM 20

C. MODEL DEMONSTRATION/VERIFICATION 25

V. DYNAMIC TARGET SELECTION MODEL (MODEL III) 32

A. INTRODUCTION 32

B. MODEL ALGORITHM 33

C. MODEL RESULTS AND ANALYSIS 36

1. INDIVIDUAL FACTOR COMPARISONS 39

    a. EFFECT OF PK VARIATIONS 39

    b. SHORTEST ROUTE COMPARISON 40

    c. LEAST DIFFICULTY COMPARISON 40

2. EFFECTS OF AIR DEFENSE LETHAL RADII REDUCTIONS . 41

3. EFFECTS OF WEIGHT SETS 42

VI. SUMMARY AND FUTURE RESEARCH AREAS 44

APPENDIX A. RESULTS (TABLES) OF DYNAMIC TARGET SELECTION MODEL 46

APPENDIX B. FACTOR COMPARISON OF DYNAMIC TARGET SELECTION MODEL RESULTS 89

APPENDIX C. LIST OF VARIABLES 104

APPENDIX D. SOURCE CODE OF AIR GRID COVERAGE MODEL (MODEL I) 107

APPENDIX E. SOURCE CODE OF AIR ROUTE SELECTION MODEL (MODEL II) 135

LIST OF REFERENCES 147

INITIAL DISTRIBUTION LIST 148

LIST OF TABLES

TABLE 1. Results of Cases 1-3 15

TABLE 2. Results of Cases 4-6 16

TABLE 3. Results of Combined Case 18

TABLE 4. Results of Difficulty Set 1 28

TABLE 5. Results of Difficulty Set 2 30

TABLE 6. Results of Difficulty Set 3 31

TABLE 7. PK set 2 of Node set 2 38

TABLE 8. Weight Sets 38

LIST OF FIGURES

Figure 1. FTLM Architecture 3

Figure 2. Possible Movements Out of Grid 6 6

Figure 3. Numerical Integration Using Modified Trapezoidal Rule 12

Figure 4. Ground Nodes : Cases 1-6 14

Figure 5. Ground Nodes : Multiple Coverage 17

Figure 6. TAC THUNDER Ingress/Engress Route 19

Figure 7. Routes to Target Grid 13 - Difficulty Set 1 27

Figure 8. Routes to Target Grid 25 - Difficulty Set 2 29

Figure 9. Routes to Target Grid 25 - Difficulty Set 3 29

Figure 10. Ground Node Set 1 37

Figure 11. Ground Node Set 2 37

EXECUTIVE SUMMARY

The purpose of the research presented in this paper is to design, develop, implement and test dynamic air route selection modules for use in the Future Theater-Level Model (FTLM) being developed at the Naval Postgraduate School. FTLM is a stochastic simulation model which focuses on perceptions developed from dynamic intelligence reports and the resultant actions taken by each side based on these perceptions. The model utilizes an arc-node representation for both the ground and air portions of the battlefield.

Three models comprise the dynamic air route selection package. Model I computes the portion of each square air grid covered by a selected characteristic radius of each ground unit. In addition, it computes an estimate of the potential lethality to the flight group (Difficulty Level) by that ground unit in each air grid for use in Model II. Several test calculations are shown to assure correct geometry logic, especially at the grid boundaries.

Model II dynamically selects ingress (and separate) egress routes from flight group air rendezvous points to a designated air grid which may be a target, reconnaissance area, or orbit location. This selection is made using dynamic programming and priority queue techniques considering both travel time or distance and Difficulty Level due to **perceived** enemy air defense threats. Again, several test runs are shown to assure that

the algorithms are behaving reasonably.

Model III **simultaneously** selects a target from several candidates, selects a route and determines the implications of various escort aircraft levels in an optimal fashion. The selection is made based on the relative weight assigned to travel time or distance, Difficulty Level, and Target Priority. Models I and II are run internally to Model III, with potential targets and their priorities as additional inputs.

Even though these models were developed primarily for use in FTLM, they can be very useful in a stand-alone mode for an Air Operations planner. Results and analyses are presented to illustrate a few of the many variants which these models can portray. The interested reader is encouraged to contact Professor Parry at the Naval Postgraduate School for the PASCAL codes.

I. INTRODUCTION

The purpose of the research presented in this paper is to design, develop, implement and test dynamic air route selection modules for use in the Future Theater-Level Model (FTLM) being developed at the Naval Postgraduate School. FTLM is a stochastic simulation model which focuses on perceptions developed from dynamic intelligence reports and the resultant actions taken by each side based on these perceptions. The model utilizes an arc-node representation for both the ground and air portions of the battlefield. A brief background and motivation for this research is given in Chapter II.

Three models comprise the dynamic air route selection package. Model I, described in Chapter III and Appendix D, computes the portion of each square air grid covered by a selected characteristic radius of each ground unit. In addition, it computes an estimate of the potential lethality to the flight group (Difficulty Level) by that ground unit in each air grid for use in Model II. Several test calculations are shown to assure correct geometry logic, especially at the grid boundaries.

Model II dynamically selects ingress (and separate) egress routes from flight group air rendezvous points to a designated air grid which may be a target, reconnaissance area, or orbit location. This selection is made using dynamic programming and priority queue techniques considering both travel time or distance and Difficulty Level due to **perceived** enemy air defense threats. Model II is presented in Chapter IV and Appendix

E. Again, several test runs are shown to assure that the algorithms are behaving reasonably.

Model III, described in Chapter V and Appendices A, B, **simultaneously** selects a target from several candidates, selects a route and determines the implications of various escort aircraft levels in an optimal fashion. The selection is made based on the relative weight assigned to travel time or distance, Difficulty Level, and Target Priority. Models I and II are run internally to Model III, with potential targets and their priorities as additional inputs.

Even though these models were developed primarily for use in FTLM, they can be very useful in a stand-alone mode for an Air Operations planner. Results and analyses are presented to illustrate a few of the many variants which these models can portray. The interested reader is encouraged to contact Professor Parry at the Naval Postgraduate School for the PASCAL codes.

II. BACKGROUND

Most theater-level combat models currently in use share common characteristics; they are low resolution, highly aggregated, and attrition-based; they also depict combat as a deterministic phenomenon. The shortcomings of these models are that their outputs generally do not represent the expected value results of combat engagements; they tend to exhibit large sensitivity to small changes in input; and they provide no measure of uncertainty in the outputs. Thus, the current theater-level models fail to represent the uncertainty inherent in predicting the outcome of a theater campaign. As scenarios grow increasingly uncertain, current models cannot support analyses that examine many different possible outcomes and their impact on national military policies. [Ref. 1:p 1]

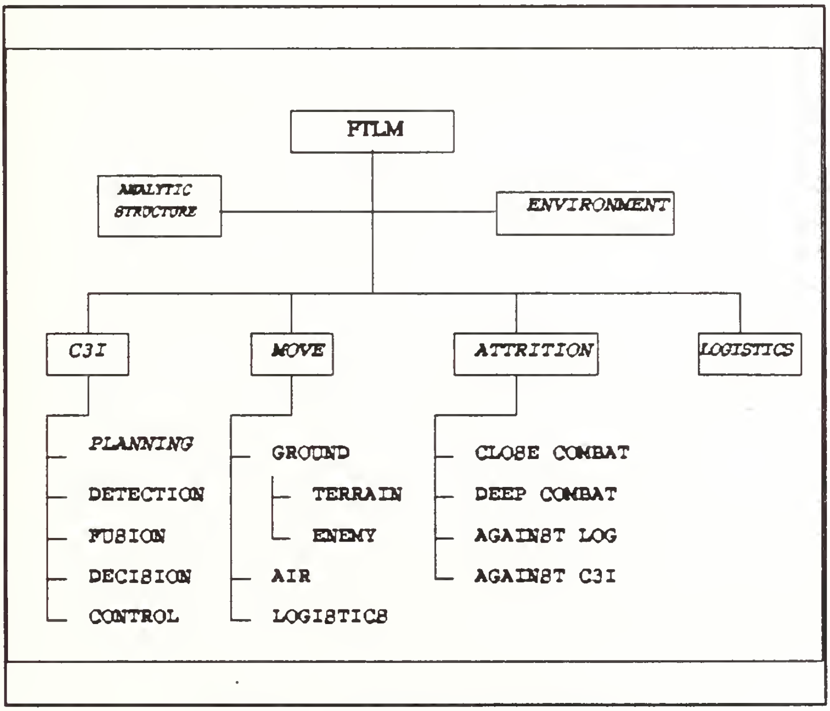

Figure 1. FTLM Architecture

In order to correct the deficiencies of current models, a research effort to develop the Future Theater-Level Model (FTLM) is ongoing at the Naval Postgraduate School. FTLM is a symbolic model characterized by its aggregated, stochastic, information-intensive, and dynamic nature [Ref. 2:p 23]. The thesis by Karl Schmidt [Ref. 3] currently provides the most complete description of FTLM in one document.

FTLM has several functional modules as shown in Figure 1. A paper by Mark Youngren [Ref. 4] includes additional details on the various modules.

A. GROUND NETWORK AND UNITS

All movements of ground and air forces in FTLM occur on two arc-node networks: ground and air. The ground network design has two different types of nodes: physical and transit. The reason for this representation is that a unit will always exist at a node at every point in time, and once a unit leaves a physical node, it will be processed as if it exists at the transit node. Physical nodes may be located at critical intersections, geographic points of interest, air bases, logistics facilities, probable defensive battle positions, assembly areas, etc. Transit nodes are surrogates for arcs in a usual network representation. Transit nodes have several attributes such as distance, on-road and off-road terrain characteristics, and size of mobility corridors. [Ref. 5:p 2]

Ground units, as well as physical nodes, also have many attributes. Those attributes of primary interest in this thesis are described by circles centered at either the actual or perceived unit location. These circles represent factors such as physical area occupied, maximum effects areas for direct fire weapons, maximum detection range of other ground units, maximum air defense radar range, lethal areas of air defense sites against various aircraft types, etc. Again, the reader is referred to Schmidt's thesis for additional details on the ground model.

B. AIR NETWORK AND UNITS

> The goal of the Air Module design is to provided a dynamic representation of the functions required for air-air, air-ground, and ground-air activities at a level of resolution commensurate with the overall design objectives of FTLM. [Ref. 6:p 1]

The air network is a square grid system which is geometrically and logically related to the ground network. The size of the grid squares can vary depending on the resolution required and the fidelity of the ground network for each application. In any case, each air grid has the same area. The primary purpose for using an air grid is to facilitate a flight group's selection of ingress and egress routes to target and/or reconnaissance areas.

The paths of flight groups (which are made up of possibly several flights, each having any number of one aircraft type) are from center to center of air grids. Movement out of a grid may occur in any one of eight directions (see Figure 2 at p. 6). It is important to note that, even though a flight group is pictured at a grid center, the processing algorithms actually represent the flight groups in essentially continuous time. The overall ingress and egress routes of a given flight group are sequential lists of grids from the base of origin to the chosen destination, and back to a designated base, probably using a route different from ingress.

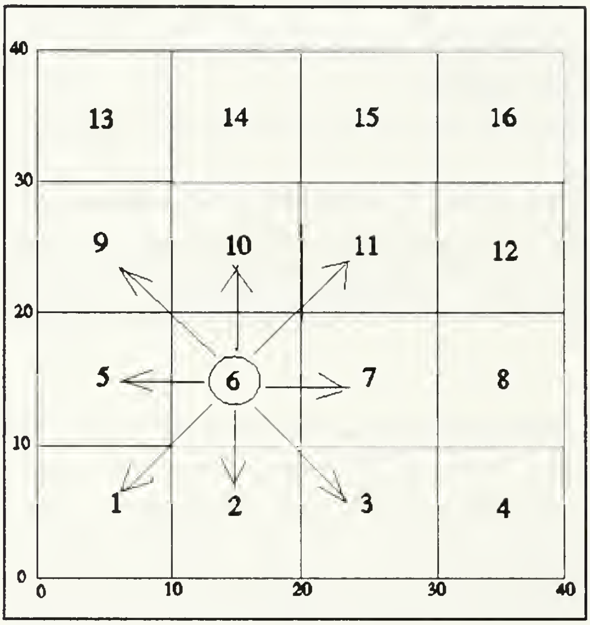

Figure 2. Possible Movements Out of Grid 6

Additional characteristics of the FTLM air model are given in Reference 3 (p.71-82). Because the air portion is currently in the final design and initial implementation phase, changes occur on a daily basis. Therefore, additional general descriptions at this point in its development would not be productive.

III. AIR GRID COVERAGE MODEL (MODEL I)

A. INTRODUCTION

Recall that FTLM uses physical and transit nodes to represent locations and movement of ground units. Several characteristics of ground units are described by circles centered at the ground unit location, such as physical area occupied, maximum effects area for direct fire weapons, maximum detection range of other ground units, etc. Other characteristics similarly represented are maximum radar range for air defense (AD) sites acquiring air flight groups, maximum lethal areas of AD sites against various aircraft types, etc.

Because of the stochastic nature of FTLM, it is often required to compute the portion of a specified area (either air or ground) covered by a particular area characteristic of a unit at a ground node. For example, even though air flight groups are always located at the center of an air grid, the algorithms of FTLM process the groups as if they are continuously moving through the center of the grid. In order to assess effects of ground AD sites engaging flight groups, the portion of the air grid subject to AD detection and firing is required.

Given **N** ground units, each with a specified characteristic area, and **M** square air grids, Model I computes the portion of each air grid covered by each of the **N** ground units. In addition, the module computes an estimate of the potential lethality of that ground unit against a flight group in each air grid; this estimate is called the Difficulty Level, for use in the Air Route Selection module (Model II) presented in Chapter IV.

B. MODEL ALGORITHM

Data in the form of perceived information concerning the location and characteristics of each ground unit are available as inputs to Model I. It is important to note that perceived data are used for planning processes (such as determining ingress and egress routes), while ground truth data are used when adjudicating combat outcomes.

The following variables are used in the module:

- PK[i,j] = the Probability of Kill of a target in air grid i with respect to ground unit j
- DL[i] = the Difficulty Level (Probability of Kill) of a target in air grid i with respect to all ground units, that is DL[i] = Σ_j PK[i,j]
- r_j = the radius of ground unit j for the desired characteristic
- TAC[i] = the total area of air grid i covered by all ground units
- AC[i,j] = the area of air grid i covered by ground unit j
- Area = area of each air grid

Let P[j] be the estimated probability of kill for the j^{th} ground unit against a potential target of interest. Because P[j] is a planning factor based on the **perceived** air defense capability of the j^{th} ground unit against a heterogeneous mix of aircraft types in a flight group, it is an input value which only depends on the type of air defense systems perceived to be in the j^{th} ground unit. Obviously, when attrition assesments are made during actual flight, individual aircraft types and ammunition types are considered. Thus, PK[i,j] is computed by equation (1):

$$PK[i,j] = \frac{(\,P[j] \times AC[i,j]\,)}{Area} \qquad (1)$$

Definition of variables used in the PASCAL CODE for Models I and II are presented in Appendix C.

Model I is described below in pseudo-code. A complete listing of the Pascal code for Model I is given in Appendix D.

Input : Ground node/unit file (perceived information) of the opposing side consists of coordinates of the center point of a circle corresponding to the ground unit, radius of the circle of maximum effect area of the ground unit, and the estimated probability of kill for the ground unit.

Output : DL[i] and TAC[i] for i = 1..M

```
1. initialize DL[i], PK[i,j], TAC[i], and AC[i,j] to 0, ∀ i = 1..M, j = 1..N
2. while (input file is not empty)
3.   { read one data point j from the ground node/unit file
4.      find the location of the center of the circle of the ground node j
5.      if (center point of ground node j is inside a specific air grid S)
{for example, in Figure 4, the center point of case 3 is inside air grid 11, but center points of cases 1 and 2 are not inside an air grid; rather they are on the line shared by air grids 1 and 2}
```

```
6.      if (area covered by the ground node j is totally inside the air grid S)
```

{if the radius of case 3 is reduced below 0.5 (current radius is 0.7071) at Figure 2, it will be totally inside air grid 11; that is, S = 11. Code lines 7 - 10 perform the calculation for this situation.}

```
7.          then AC[S,j] ← $\pi * r_j^2$
8.                  PK[S,j] ← (P[j] * AC[S,j]) / Area
9.                  TAC[S] ← TAC[S] + AC[S,j]
10.                 DL[S] ← DL[S] + PK[S,j]
```

{There will be some overlaps of area in the calculation of TAC[S] in code line 9 (or TAC[i] in following lines of code) in some cases. For example, considering air grid 11 of Figure 4; it is covered by cases 3, 5, and 6. This result is correct since each is generated from different ground units and each individual ground unit will have its own effect on the air grid S (or i)}

{Code lines 11 - 14 perform the caculation for the case that the center of ground node j is inside a specific air grid S, but is not totally contained in air grid S. For example, case 3 in Figure 4, S = 11 and i = 7, 10, 12 and 15. A ***modified TRAPEZOIDAL RULE*** *[Ref. 7: p. 336] is used to estimate the integral of the area covered for each air grid i, except S. The covered area is divided into trapezoids with equal width, but the height for each trapezoid is different from that of the Trapezoidal rule; the height at the middle point of each individual trapezoid is used instead of the average height of the curve. Grid 15 and case 3 of Figure 4 are used to show how the modified Trapezoidal*

rule works (see Figure 3 at p. 12). This is also the most time consuming part of the program, depending on the required accuracy of the result.}

```
11.       else  calculate AC[i,j], $\forall i \neq S$
12.            PK[i,j] ← (P[j] * AC[i,j]) / Area
13.            TAC[i] ← TAC[i] + AC[i,j]
14.            DL[i] ← DL[i] + PK[i,j]
```

{Code lines 15 - 18 are for the situation when the center of a ground node is either on an air grid boundary or outside the entire air grid space (case 2 in Figure 4). The portions of the areas outside the air grid system are omitted.}

```
15.    else  calculate AC[i,j], $\forall i = 1..M$
16.         PK[i,j] ← (P[j] * AC[i,j]) / Area
17.         TAC[i] ← TAC[i] + AC[i,j]
18.         DL[i] ← DL[i] + PK[i,j]
```

{Code lines 19 - 28 will perform the caculations for the remaining cases.}

```
19.    if (area covered by the ground node is not totally inside air grid S)
20.      if (center point of the ground node is inside an air grid S and area covered by
           the ground node is not out of boundary)
```

{for example, in Figure 4, case 3 is not out of boundary and code lines 21 - 24 compute the area for air grid S.}

```
21.        then AC[S,j] ← $\pi * r^2 - \sum_{i \neq S}$ AC[i,j]
22.            PK[S] ← (P[j] * AC[S,j]) / Area
23.            TAC[S] ← TAC[S] + AC[S,j]
```

```
24.             DL[S] ← DL[S] + PK[S]
```

{If the radius of case 3, Figure 4, is expanded to greater than 1.5, the ground node will exceed the air grid space boundary. Code lines 25 - 28 consider this case.}

```
25.     else calculate AC[S,j] with boundary check procedure
26.         PK[S,j] ← (P[j] * AC[S,j]) / Area
27.         TAC[S] ← TAC[S] + AC[S,j]
28.         DL[S] ← DL[S] + PK[S,j]
29.     }
```

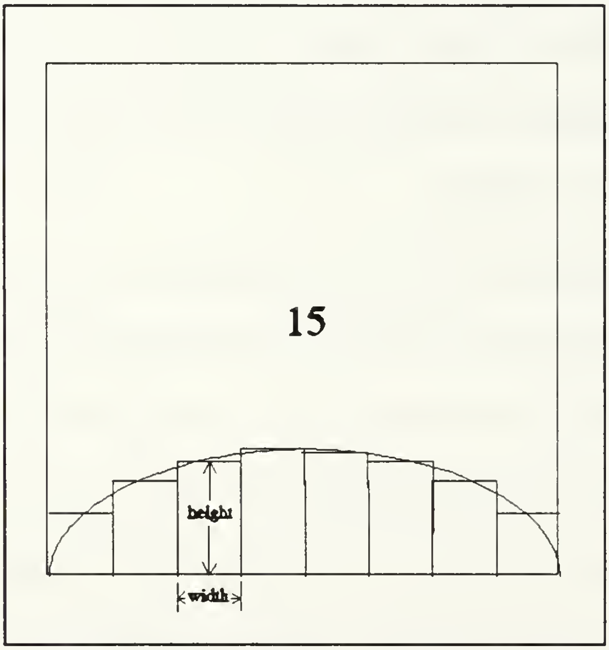

Figure 3. Numerical Integration Using Modified Trapezoidal Rule

C. MODEL DEMONSTRATION/VERIFICATION

1. VERIFICATION

Several geometric cases of the location of ground unit areas relative to air grids arise. Six cases as shown in Figure 4 are used to verify the code (i.e., to compute the Difficulty Level (DL) and Total Area Covered (TAC) for all grids). This algorithm can take care of any geometric case as long as the center point is inside the grid system. As indicated in the pseudo-code, an adaptation of the Trapezoidal rule [Ref. 7: p. 336] is used with a 10 meter distance interval, Δd, which provides sufficient accuracy for the covered area computation. For this verification and demonstration, a 4 x 4 square air grid matrix is used, with each grid being 10 KM on a side; the grid is displayed in Figure 4.

Tables 1 and 2 present the results of the six verification cases, three cases per table. The notation used in these tables for the ground node is (X,Y,R,P) where X,Y is the ground unit center, R is the radius of the characteristic circle of interest, and P is the probability of kill. Two columns are shown for each air grid for each case: TA is total area covered and DL is the Difficulty level. Note that P[j] has been set to 1.0 for these verification runs. In each case, the computed area was checked by hand calculations to assure they were correct.

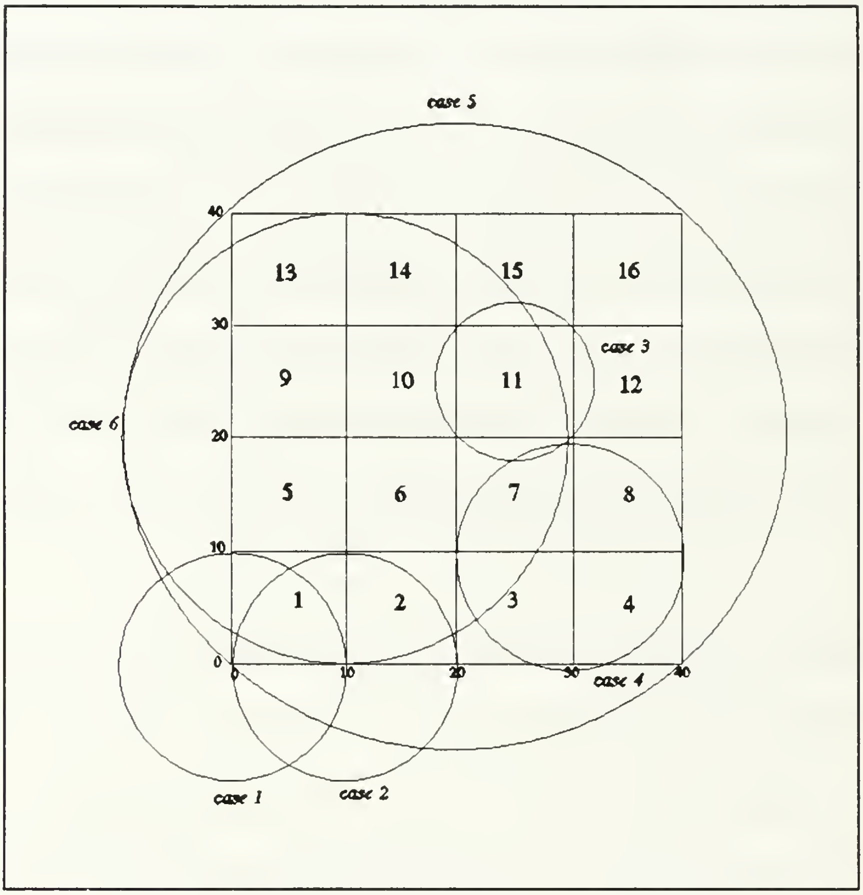

Figure 4. Ground Nodes : Cases 1 ~ 6

Table 1. Results of Cases 1-3

	CASE 1		CASE 2		CASE 3	
	X Y R P 0 0 10 1		X Y R P 10 0 10 1		X Y R P 25 25 7.07 1	
grid #	DL	TAC	DL	TAC	DL	TAC
1	0.79	78.50	0.79	78.50	0	0
2	0	0	0.79	78.50	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0.14	14.27
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0.14	14.27
11	0	0	0	0	[illegible]	100
12	0	0	0	0	0.14	14.27
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0.14	14.27
16	0	0	0	0	0	0

Table 2. Results of Cases 4-6

	CASE 4		CASE 5		CASE 6	
	X Y R P		X Y R P		X Y R P	
	30 9.999 10 1		20 20 28.284 1		10 20 20 1	
grid #	DL	TAC	DL	TAC	DL	TAC
1	0	0	1	100	0.91	91.30
2	0	0	1	100	0.91	91.30
3	0.79	78.54	1	100	0.32	31.50
4	0.79	78.54	1	100	0	0
5	0	0	1	100	1	1
6	0	0	1	100	1	1
7	0.79	78.54	1	100	0.91	91.30
8	0.79	78.54	1	100	0	0
9	0	0	1	100	1	1
10	0	0	1	100	1	1
11	0	0	1	100	0.91	91.30
12	0	0	1	100	0	0
13	0	0	1	100	0.91	91.30
14	0	0	1	100	0.91	91.30
15	0	0	1	100	0.32	31.50
16	0	0	1	100	0	0

2. DEMONSTRATION

This section demonstrates Model I when multiple ground areas cover the same air grid. Note from Figure 5 and Table 3 that the third unit (with radius 28.28) has been selected to cover the entire air grid matrix, while the first two cover portions of air grids 1 and 2. In this case, note that TAC can exceed the total grid area. Also, different values of P[j] as noted in Table 3 are used for each ground area. The resulting values of Difficulty Level and Total Area Covered are given in Table 3. As before, these values were verified by hand calculations.

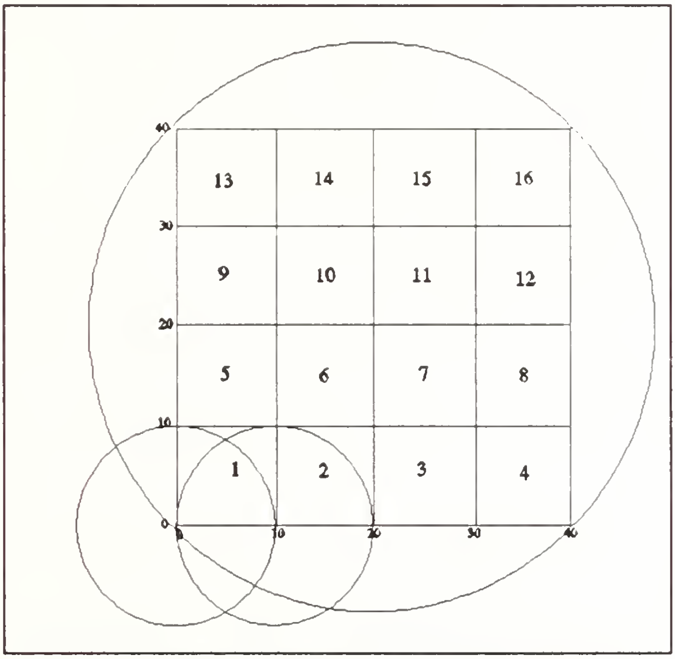

Figure 5. Ground Nodes : Multiple Coverage

Model I is an important part of FTLM and is called many times during the course of a model run. The module has been implemented in FTLM by the contractor programmer and has been verified in the model. It is currently used for assessing ground-to-air attrition and will be used for several other applications in the future.

Table 3. Results of Multiple Coverage

	PERCEIVED GROUND UNIT DATA			
	X	Y	R	P
node 1	0	0	10	0.5
node 2	10	0	10	0.3
node 3	20	20	28.28	0.2

grid #	DL	TAC
1	0.83	257.08
2	0.44	178.54
3	0.20	100.00
4	0.20	100.00
5	0.20	100.00
6	0.20	100.00
7	0.20	100.00
8	0.20	100.00
9	0.20	100.00
10	0.20	100.00
11	0.20	100.00
12	0.20	100.00
13	0.20	100.00
14	0.20	100.00
15	0.20	100.00
16	0.20	100.00

IV. AIR ROUTE SELECTION MODEL (MODEL II)

A. INTRODUCTION

Recall that Flight Groups in the FTLM air model fly from the center of a square air grid to the center of one of eight adjacent grids. Existing models, such as TAC THUNDER, compute the ingress route from the air base to the target grid as shown in Figure 6.

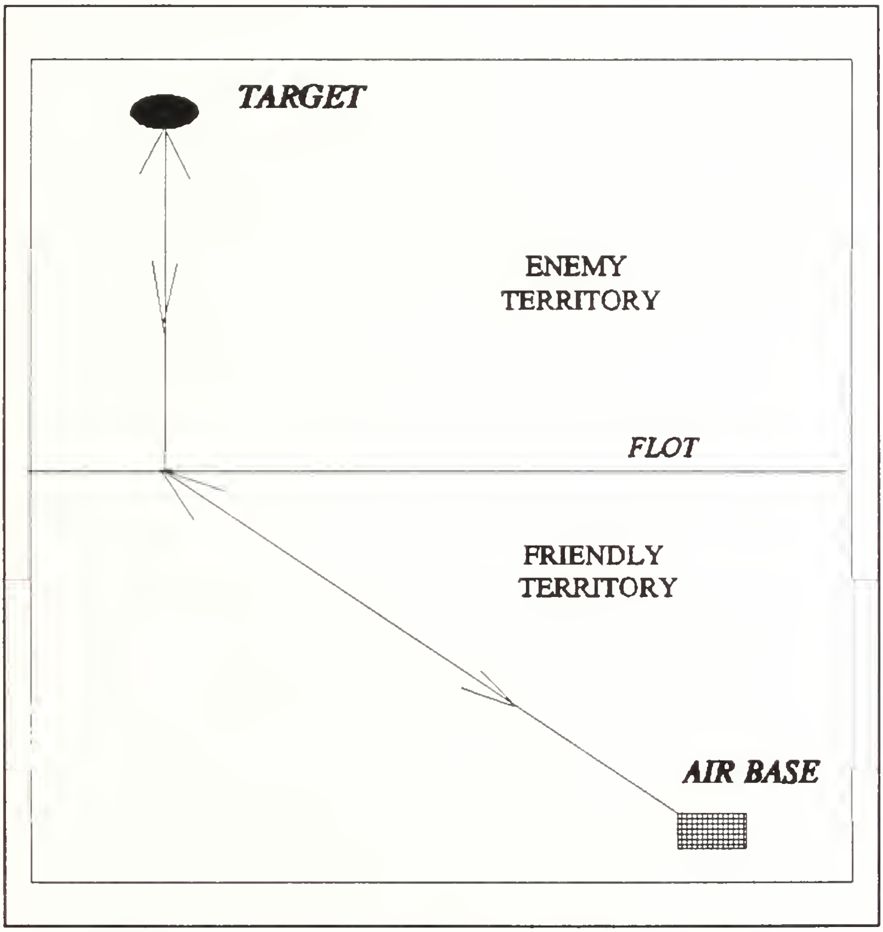

Figure 6. TAC THUNDER Ingress/Engress Routes

The forward-line-of-troops (FLOT) separates friendly and enemy territory. A line is drawn from the target perpendicular to the FLOT, giving the shortest distance flown over enemy territory. A straight line connecting the air base (or the air rendezvous point for the flight group) with that location on the FLOT completes the ingress route. That same route is also used for egress from the target. Some version of this method is used in other existing theater-level models.

The TAC-THUNDER approach is not appropriate for FTLM for the following reasons. First, there is no specific FLOT representation in FTLM, because anticipated future scenarios will likely not be FLOT oriented. Secondly, the approach does not consider the **perceived** location of possible air or ground air defense threats. Finally, there is no capability to represent a sequence of target areas.

The Air Route Selection Module (referenced as Model II in this paper) for FTLM will dynamically select ingress (and separate egress) routes from flight group air rendezvous points to designated target, reconnaissance, or orbit locations considering both travel time/distance and difficulty level due to **perceived** enemy air defense threats.

B. MODEL II ALGORITHM

Model II determines the route from any air grid to a designated destination air grid which is the optimal route based on the minimum weighted sum of distance, measured in air grid units (AGU), and cumulative difficulty, as determined by Model I. The algorithm, described later in this section, uses dynamic programming and priority queue techniques to determine the optimal route [Ref. 7:p. 515].

The objective function is the minimum cumulative weighted value of distance and difficulty from the current grid to the target grid [Ref. 8]. The measurement of distance in air grid units (AGU) means that the distance to an air grid adjacent horizontally or vertically is one unit; whereas the distance to an air grid diagonally adjacent is 1.414 units. For example, in Figure 7, P. 27, the distance of route path 1-6-11-16-21 would be 4.0, whereas the route 1-7-11-16-21 would be 4.828. This scaling is used so that the relative units of distance and difficulty are of the same order of magnitude. It should be noted that this scaling produces the same relative values of distance and difficulty for any air grid size. For example, if the grid of Figure 7 had grids 5 KM on a side (instead of 10 KM) the number of grids would increase to 100 (instead of 25). Any given route would then be twice as long as the original route (as measured in AGU) but the difficulty would also double since twice as many difficulties are being accumulated. Also, the normalization procedures described in Chapter V produce normalized values of distance and difficulty which are indedependant of air grid size. Thus, the same route would be selected for either air grid configuration.

The process begins at the target grid and uses a backward pass through the dynamic program. The structure of this problem is different from the usual dynamic programming and single-source shortest-paths problems. In regular dynamic programming, one optimal route is determined for a specific starting grid; but here an optimal route is determined from **all** air grids to the target grid. This algorithm is also different from single-source shortest-paths problems in which *Dijkstra's algorithm* [Ref. 7: p. 527] is used to find a shortest path from a given grid to all other grids. Here, a shortest path to a given target grid from every other grid is required. This enhancement is needed in the case of multiple starting grids or when a sequence of target areas must be considered. Thus, a priority queue is used to keep track of the **minimal** cumulative weighted value of distance and difficulty as a sorting basis. The grid with the smallest value is explored first at each stage of the dynamic program. Several examples of the algorithm are given in Section C.

Model II is described below in pseudo-code. Note that the difficulty level for each air grid is computed by Model I and is input to Model II. Definition of the variables used in the algorithm precede the pseudo-code. The complete listing of the Pascal code is given in Appendix E.

- **M** is total number of air grids
- T is target grid
- w_1 is the weight of travel time/distance
- w_2 is the weight of Difficulty Level, where $w_1 + w_2 = 1$
- Hardness[i] is the cumulative value of weighted travel time/distance and Difficulty Level, from air grid i to target grid T, for i = 1,..., **M**
- visited[i] is a *boolean variable* to indicate whether grid i has been explored or not, $\forall$ i = 1,..., **M**
- next_choice[i] is an *integer variable* to show what is the best move for the next step for grid i, $\forall$ i = 1,..., **M**

The data for Hardness, visited, next_choice, and the distance between adjacent grids are stored in adjacency list form.

Input : value of Difficultly Level (DL) of each grid (result computed by Model I)

Output : Minimal value of Hardness[i] and the routes for all air grids i to target grid T, $\forall$ i = 1,..., **M**

```
1. { Initialize : 1. PriorityQueue
                  2. visited[i] := false, $\forall i = 1,\ldots, \mathbf{M}$
                  3. next_choice[i] := $\mathbf{M} + 1, \forall i \neq T$
                  4. grid[T].next_choice := 0
                  5. Hardness[i] := $\infty, \forall i \neq T$
                  6. Hardness[T] := 0
2. put T into PriorityQueue
{Air grid i, with smallest Hardness value, is placed at the top of the PriorityQueue; for
details, see example in Section C and procedure InsertPriorityQueue of unit PriQTool
in Appendix F, p.146}
3. while (PriorityQueue is not empty)
{The process finishes if there is no entry inside the Queue; for details see function
EmptyPriorityQueue of unit PriQTool in Appendix F, p.146}
4.   { remove grid j from the front of the PriorityQueue
5.       for (each grid i incident to grid j)
6.         { if (j = T)
7.             { grid[i].Hardness := $w_2$ * Hardness[T] + $w_1$ * (Distance between T
                 and i)
8.               next_choice[i] := T
9.               visited[i] := true
```

```
       put grid i into PriorityQueue
    }
else
  { min := $\infty$
    choice := M + 1
    if (visited[i] = false)
      { for (each grid u incident to grid i)
           { if (visited[u]= true)
                { Hardness := Hardness[u] + $w_2$ * DL[u] + $w_1$ * (Distance
                 between u and i)
                 if ( Hardness < min )
                   { min := Hardness
                     choice := u
                   }
                }
            }
        visited[i] := true
        Hardness[i] := Hardness
        next_choice[i] := choice
        put grid i into PriorityQueue
      }
```

```
        }
    }
}
```

C. MODEL DEMONSTRATION/VERIFICATION

Three different cases are used to demonstrate and verify Model II. In each case, a 5 x 5 air grid is used, each grid being 10 KM on a side. The values of the weights are set to $w_1 = 0$ and $w_2 = 1$ in order to verify that the minimum difficulty route (not considering distance) is chosen. In the next chapter, many runs with different values of w_1 and w_2 are described and analyzed. The results of each case are given in Tables 4, 5, and 6. Each table has four columns. Column 1 is the starting grid number; column 2 gives the difficulty for that grid computed by Model I; column 3 gives the optimal path to the target; and column 4 gives the total weighted value of distance and difficulty (which is only minimum difficulty for these cases). Cases 1 and 2 use the air grids shown in Figures 7 and 8, respectively, with Case 1 having grid 13 as the target and Case 2 using target grid 25. Case 3 uses the grid shown in Figure 9 which has different difficulties from the previous cases, and has grid 25 as the target grid. Note that the figures show the grid number and the difficulty computed by Model I in each air grid.

To illustrate the algorithm in detail, the initial iterations for Case 1 are described. All of the locally optimal route possibilities to grid 13 are shown in Figure 7. There are two numbers in each individual grid; the top one represents the grid number, and the bottom number indicates the Difficulty Level (DL) computed by Model I. The arrow in each grid represents the best choice for next step.

The process begins with those grids incident to target grid 13 and computes the Hardness for each one. Because of the data structure, grid 18 is the first grid processed (the order is immaterial). The optimal route is 18 ⇒ 13 and Total DL (Hardness) is $w_1 * DL[13] + w_2 *$ (distance between 13 to 18) = $1.0 * 1.6 + 0.0 * 1 = 1.6$. Grid 18 is put into the PriorityQueue with sorting index 1.6 + DL[18] = 1.6 + 0.3 = 1.9. The same procedure is used for grids 19, 14, 9, 8, 7, 12, and 17. For example, the total DL of grid 19 is $1.0 * 1.6 + 0.0 * 1.414 = 1.6$; the optimal route is 19 ⇒ 13 and 1.6 + 2.5 = 4.1 is used as the sorting index. After processing all grids adjacent to grid 13, the order of the Priority Queue (from smallest sorting index to highest sorting index) is 9 → 18 → 8 → 17 → 14 → 12 → 7 → 19. Next, select the first grid in the Priority Queue (grid 9) and process those grids incident to grid 9. Since grid 14 had been visited, the next grid considered is grid 15. The total DL of grid 15 is $1.0 * 1.8 + 0.0 * 1.414 = 1.8$; the optimal route is 15 ⇒ 9 ⇒ 13 and grid 15 goes into the Priority Queue using 1.8 + 0.2 = 2.0 as its sorting index. The current order of the Queue is 18 → 15 → 8 → 17 → 14 → 12 → 7 → 19. After all adjacent grids to grid 9 are processed, compute the Total DL for those grids incident to grid 18. This process is continued until all grids have been considered. The result (see Table 4, p. 28) is the optimal route from any starting grid to target grid 13.

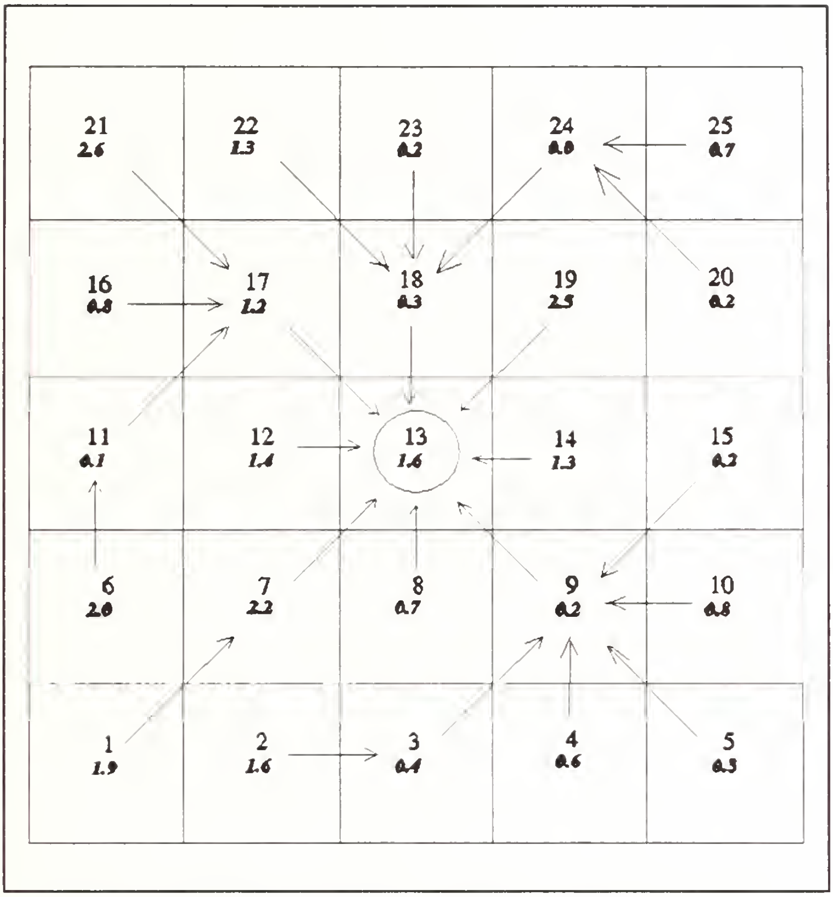

Figure 7. Routes to Target Grid 13-Difficulty Set 1

Table 4: Results of Difficulty Set 1

Case 1 : Target Grid is 13			
STARTING GRID i	DL[i]	ROUTE TO TARGET	TOTAL DL
1	1.9	1 ⇒ 7 ⇒ 13	3.8
2	1.6	2 ⇒ 3 ⇒ 9 ⇒ 13	2.2
3	0.4	3 ⇒ 9 ⇒ 13	1.8
4	0.6	4 ⇒ 9 ⇒ 13	1.8
5	0.3	5 ⇒ 9 ⇒ 13	1.8
6	2.0	6 ⇒ 11 ⇒ 17 ⇒ 13	2.9
7	2.2	7 ⇒ 13	1.6
8	0.7	8 ⇒ 13	1.6
9	0.2	9 ⇒ 13	1.6
10	0.8	10 ⇒ 9 ⇒ 13	1.8
11	0.1	11 ⇒ 17 ⇒ 13	2.8
12	1.4	12 ⇒ 13	1.6
13	1.6	13	0.0
14	1.3	14 ⇒ 13	1.6
15	0.2	15 ⇒ 9 ⇒ 13	1.8
16	0.8	16 ⇒ 17 ⇒ 13	2.8
17	1.2	17 ⇒ 13	1.6
18	0.3	18 ⇒ 13	1.6
19	2.5	19 ⇒ 13	1.6
20	0.2	20 ⇒ 24 ⇒ 18 ⇒ 13	1.9
21	2.6	21 ⇒ 17 ⇒ 13	2.8
22	1.3	22 ⇒ 18 ⇒ 13	1.9
23	0.2	23 ⇒ 18 ⇒ 13	1.9
24	0.0	24 ⇒ 18 ⇒ 13	1.9
25	0.7	25 ⇒ 24 ⇒ 18 ⇒ 13	1.9

Consider the route with starting grid 10 of Difficulty Set 3 (see Figure 9 and Table 6), and note that an extremely long distance route is selected. However, since only difficulty is considered, the route selected minimizes the total difficulty. This illustrates the fact that the user can investigate various extremes in route selection, as well as combinations of distance/difficulty weights.

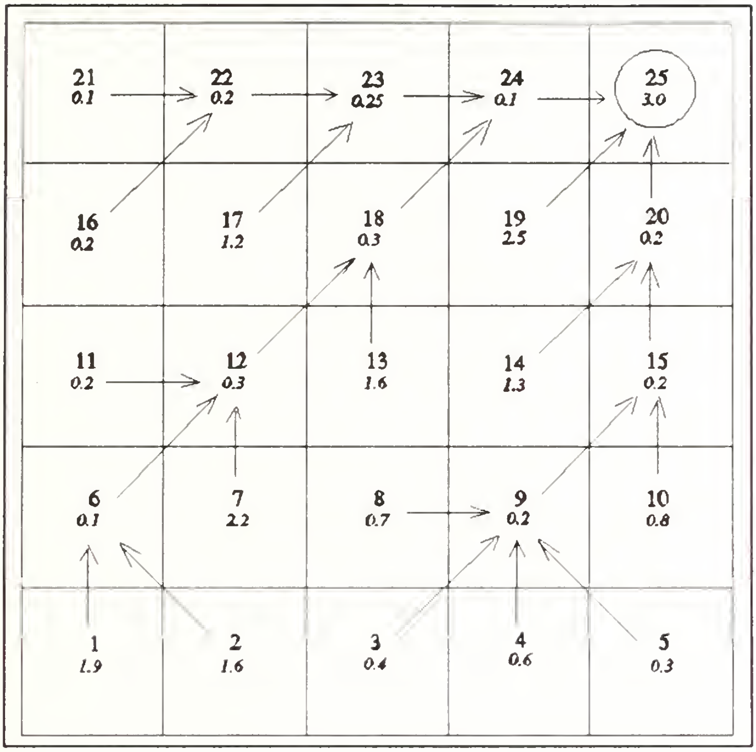

Figure 8. Routes to Target Grid 25-Difficulty Set 2

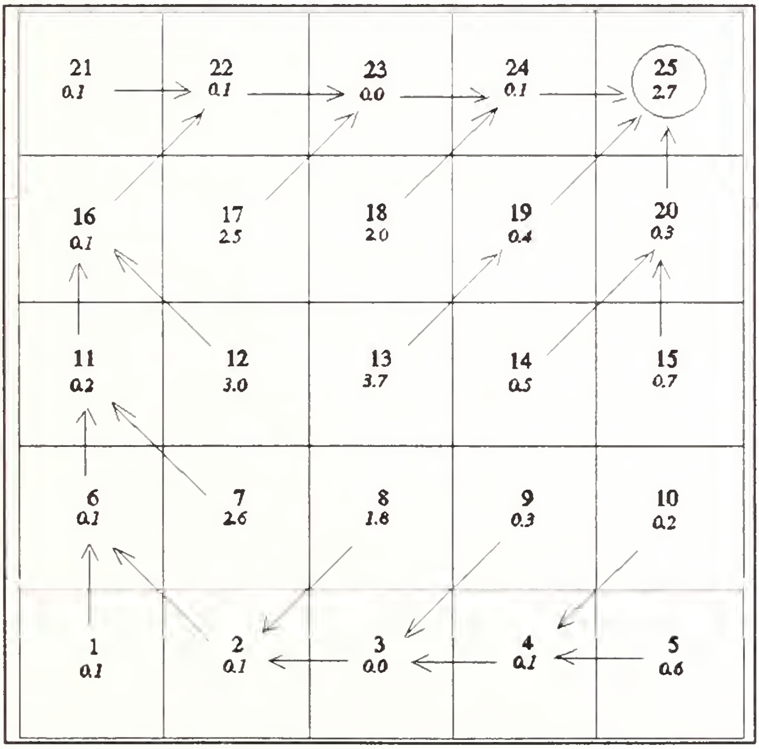

Figure 9. Routes to Target Grid 25-Difficulty Set 3

Table 5: Results of Difficulty Set 2

Case 2 : Target Grid is 25			
STARTING GRID i	DL[i]	ROUTE TO TARGET	TOTAL DL
1	1.9	1 ⇒ 6 ⇒ 12 ⇒ 18 ⇒ 24 ⇒ 25	3.8
2	1.6	2 ⇒ 6 ⇒ 12 ⇒ 18 ⇒ 24 ⇒ 25	3.8
3	0.4	3 ⇒ 9 ⇒ 15 ⇒ 20 ⇒ 25	3.6
4	0.6	4 ⇒ 9 ⇒ 15 ⇒ 20 ⇒ 25	3.6
5	0.3	5 ⇒ 9 ⇒ 15 ⇒ 20 ⇒ 25	3.6
6	0.1	6 ⇒ 12 ⇒ 18 ⇒ 24 ⇒ 25	3.7
7	2.2	7 ⇒ 12 ⇒ 18 ⇒ 24 ⇒ 25	3.7
8	0.7	8 ⇒ 9 ⇒ 15 ⇒ 20 ⇒ 25	3.6
9	0.2	9 ⇒ 15 ⇒ 20 ⇒ 25	3.4
10	0.8	10 ⇒ 15 ⇒ 20 ⇒ 25	3.4
11	0.2	11 ⇒ 12 ⇒ 18 ⇒ 24 ⇒ 25	3.7
12	0.3	12 ⇒ 18 ⇒ 24 ⇒ 25	3.4
13	1.6	13 ⇒ 18 ⇒ 24 ⇒ 25	3.4
14	1.3	14 ⇒ 20 ⇒ 25	3.2
15	0.2	15 ⇒ 20 ⇒ 25	3.2
16	0.2	16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.6
17	1.2	17 ⇒ 23 ⇒ 24 ⇒ 25	3.4
18	0.3	18 ⇒ 24 ⇒ 25	3.1
19	2.5	19 ⇒ 25	3.0
20	0.2	20 ⇒ 25	3.0
21	0.1	21 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.6
22	0.2	22 ⇒ 23 ⇒ 24 ⇒ 25	3.4
23	0.25	23 ⇒ 24 ⇒ 25	3.1
24	0.1	24 ⇒ 25	3.0
25	3.0	25	0.0

At this point, Models I and II determine the optimal route from any starting air grid to a designated target grid using user selected weights, w_1 and w_2. In the next chapter, several possible target grids and target priorities are added, resulting in Model III.

Table 6: Result of Difficulty Set 3

Case 3 : Target Grid is 25

STARTING GRID i	DL[i]	ROUTE TO TARGET	TOTAL DL
1	0.1	1 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.3
2	0.1	2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.3
3	0.0	3 ⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.4
4	0.1	4 ⇒ 3 ⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.4
5	0.6	5 ⇒ 4 ⇒ 3 ⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.5
6	0.1	6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.2
7	2.6	7 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.2
8	1.8	⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.4
9	0.3	9 ⇒ 3 ⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.4
10	0.2	10 ⇒ 4 ⇒ 3 ⇒ 2 ⇒ 6 ⇒ 11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.5
11	0.2	11 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.0
12	3.0	12 ⇒ 16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	3.0
13	3.7	13 ⇒ 19 ⇒ 25	3.1
14	0.5	14 ⇒ 20 ⇒ 25	3.0
15	0.7	15 ⇒ 20 ⇒ 25	3.0
16	0.1	16 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	2.9
17	2.5	17 ⇒ 23 ⇒ 24 ⇒ 25	2.8
18	2.0	18 ⇒ 24 ⇒ 25	2.8
19	0.4	19 ⇒ 25	2.7
20	0.3	20 ⇒ 25	2.7
21	0.1	21 ⇒ 22 ⇒ 23 ⇒ 24 ⇒ 25	2.9
22	0.1	22 ⇒ 23 ⇒ 24 ⇒ 25	2.8
23	0.0	23 ⇒ 24 ⇒ 25	2.8
24	0.1	24 ⇒ 25	2.7
25	2.7	25	0.0

V. DYNAMIC TARGET SELECTION MODEL (MODEL III)

A. INTRODUCTION

In real world generation of air missions, planners simultaneously consider target priority, anticipated travel distance to target, and expected aircraft survivability along the route and in the target vicinity. In current models, the target selection planning process is separate from specific consideration of the route. Some models contain factors such as expected aircraft attrition associated with a given target type, representing possible air defenses in the target vicinity. To the author's knowledge, no current model attempts to select a target, a route, and determine the implications of various escort aircraft levels simultaneously, and do it in an optimal fashion. That is precisely what Model III accomplishes as will be explained in this chapter, along with the results and analyses of several model runs.

Briefly, Model III begins with a list of potential targets and their priorities computed based on **current perceptions** of those possible targets. Possible methods for computing these priorities for different mission types are currently being developed by two students at the Air Force Institute of Technology (AFIT). It is anticipated that their research results will be used to determine potential targets and priorities.

As a result of whatever scheme is used to compute target priority, each target is assigned a priority value on the interval [0,100], which becomes an input to Model III. Because target priority, as well as distance and difficulty, are normalized using the largest values of each, the scales become dimensionless values. As later discussed, the magnitude of the scale chosen for target priority is closely related to the weight assigned to that attribute. For each target on the list, Model II determines the optimal route from any starting grid to that target. The user specifies three weights (distance, difficulty, and target priority) to be used. These weights are likely to be situation dependent and may well be dynamic user inputs during a run of FTLM. The result is the selection of that target with the minimum weighted sum of distance, difficulty, and (100 minus) target priority. The details are given in the next section.

B. MODEL ALGORITHM

Model III has two primary inputs, in addition to those inputs required for Models I and II, as follows:

1. Weights

- w_1 = weight assigned to total distance to target, where distance to target is in air grid units (AGU) along a route.
- w_2 = weight assigned to the total difficulty of a route.
- w_3 = weight assigned to target priority
- $w_1 + w_2 + w_3 = 1$

2. Priority

- TPRIOR[k] = priority of target k on the interval [0,100], where 100 is the highest priority.

The computational steps of Model III are given below.

a. The current **perceived** difficulty of each air grid is computed by Model I.

b. A list of possible targets, including their perceived location and priority determined by the target priority algorithm, is input.

3. For each target on the list, compute the optimal route to the target from Model II, using the weights, w_1* and w_2*, for distance and difficulty, computed as follows:

$$w_1* = \frac{w_1}{(1-w_3)} \tag{2}$$

$$w_2* = \frac{w_2}{(1-w_3)} \tag{3}$$

This computation scales the original weights so that the weights, w_1* and w_2*, used in Model II sum to 1.0. Recall from Chapter IV that distance is in air grid units (AGU) and difficulty is the sum of the lethal area contribution (weighted by the estimated kill probability associated with that lethal area) of each ground node to each air grid, accumulated for all air grids on the route.

4. Compute the normalized value of distance across all targets by dividing each distance by the **largest** distance to a target, producing normalized distances on the interval [0,1]. For a given node set, PK set , and weight set, the **actual** distance and difficulty to each target for each percent reduction of initial lethal radii of air defense sites is first computed. The **largest** of these **actual** distances and difficulties are used to compute the normalized distance and difficulty. The target values are also normalized by dividing by the largest target priority value. Normalization of these values is required because each is measured on a different dimensionality scale. The determination of the

Combined Value of each target for a specified PK, node, and weight set is made on a relative basis. For example, if the longest route computed was 5.0 AGU's, then all other route distances must be expressed as a percentage of the longest route, and similarly for difficulty and target priority. This normalization is required in order to correctly apply the weights w_1, w_2, and w_3, to each factor. Determination of the largest distance, difficulty, and target priority used for normalization is illustrated in a later section. The **Combined Value, CV,** for each target is then computed as follows:

$$CV[k] = w_1 \times NDIST + w_2 \times NDIFF + w_3 \times (1 - NPRIOR) \qquad \textbf{(4)}$$

where

NDIST = Normalized distance for target, k,

NDIFF = Normalized difficulty for target, k,

NPRIOR = Normalized priority for target, k.

The target selected, along with the route from a specified starting grid to the target, is determined by the **minimum CV** for the targets. The factor (1 - NPRIOR) is used because the objective is to determine the **minimum** value of **CV**.

5. The computations in Steps 3 and 4 are made using the current estimate of the air defense threat with no suppression of those enemy assets by friendly assets. In order to estimate the effects of adding escort aircraft for suppression of enemy air defense, the process of steps 3 and 4 is repeated for various postulated escort packages. Currently, Model III accomplishes this by reducing the lethal radius of each air defense site by a specified percentage. There is no attempt in this thesis to relate a given percent

reduction in air defense threat with specific numbers and types of escort aircraft required to accomplish that level of reduction. Also, all air defense sites are reduced by the same percentage. Future enhancements to Model III should address these areas.

C. MODEL RESULTS AND ANALYSIS

The results of several variations of node sets, probability of kill (PK) sets, and weight sets are presented in this section. Two different configurations of ground nodes were designed and are shown in Figures 10 (Ground Node Set 1) and Figure 11 (Ground Node Set 2). Node set 2 presents a more difficult problem to the flight groups than node set 1, and was chosen for that reason. The difficulty for each air grid depends on which PK set is used.

Recall that PK is defined as the probability of kill of an aircraft, given that the aircraft is within the lethal radius of the air defense site. PK set 1 assumes the probability of kill for all lethal areas is 1.0. PK set 2 assigns different probabilities of kill to each ground node in Node set 1, which is the only node set for which PK set 2 is used (see Table 7).

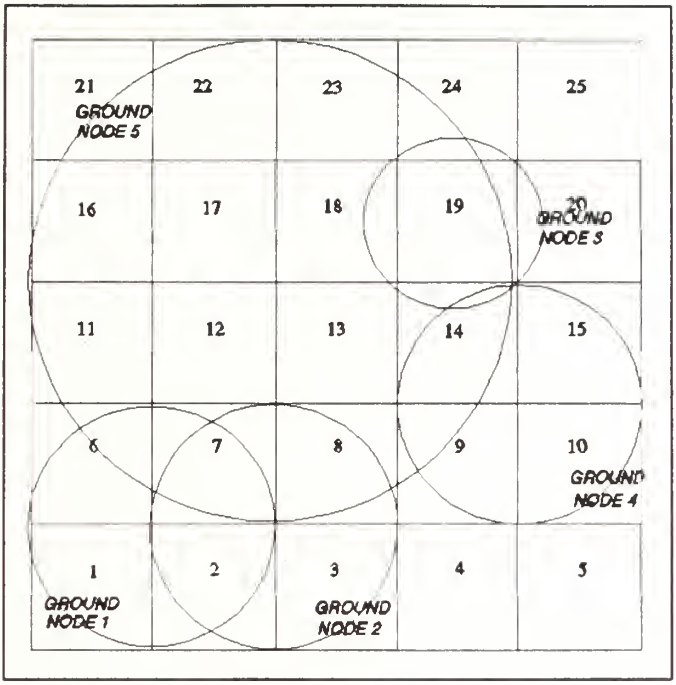

Figure 10. Ground Node Set 1

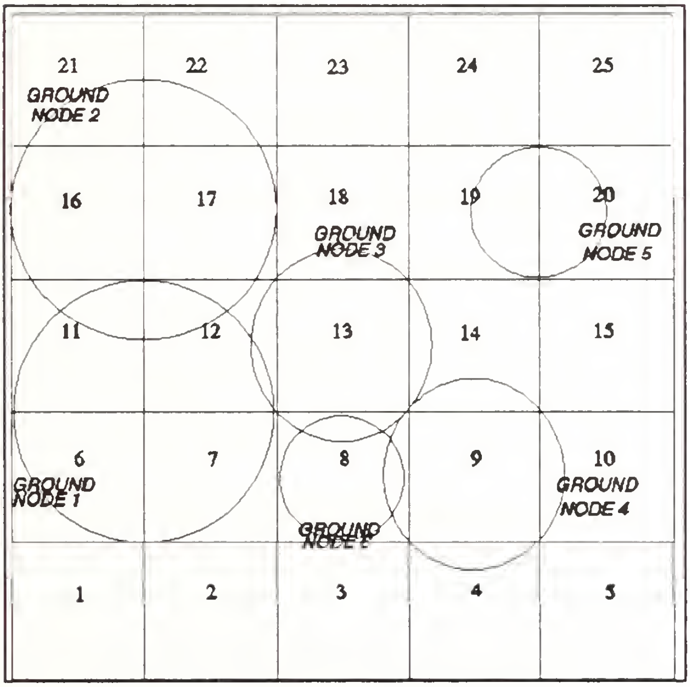

Figure 11. Ground Node Set 2

Table 7: PK Set 2

GROUND NODE	PK
1	0.9
2	0.6
3	0.8
4	0.7
5	1

Table 8: Weight Sets

WEIGHT SET	DISTANCE	DIFFICULTY	PRIORITY
1	[illegible]	0	0
2	0	1	0
3	0.33	0.33	0.33
4	0.50	0.25	0.25
5	0.25	0.50	0.25
6	0.25	0.25	0.50

Six weight sets as defined in Table 8 are used for the analysis. Note that w_1 is the weight for travel distance, w_2 for difficulty, and w_3 for target priority.

The analyses presented in this section utilize the results displayed in the tables in Appendix A. The notation used to distinguish the various cases is (**a**,**b**,**c**) where **a** is the Node set number (1,2); **b** is the PK set number (1,2) and **c** is the weight set number (1,2,3,4,5,6). Each of the tables in Appendix A shows the optimal route to each of three targets (21,23,25); the actual and normalized values of distance in AGU, difficulty, and target priority; the combined value, CV, for each target; the target selected and its CV. Three decimal place accuracy for the CV of each target is displayed because the model is indifferent between targets when values of their CV are within 0.01. These factors are presented for each of eleven percent reduction categories of the air defense sites, where the percent reduction is the percentage of the initial lethal radius of each site used for that computation.

To illustrate the determination of the **largest** value used for normalization, consider Table A.1 in Appendix A. Note that the **largest actual** value of Difficulty is 4.80 for target 25 with zero percent reduction. This value is used to normalize Difficulty for all cases in Table A.1.

Tables A.1 and A.2 use node set 1 to demonstrate the effect of reduced PK values (PK set 2). All other tables use PK set 1. Tables A.3 through A.8 use node set one across the six weight classes, while Tables A.9 through A.14 are for node set 2. The figures grouped in Appendix B are in two categories. Figures B.1 - B.8 show the changes in CV for each target across percent reduction for a specified node set and weight set. Figures B.9 - B.14 present the CV variations for node set 2 across weight sets for specified values of percent reduction.

1. Individual Factor Comparisons

a. Effect of PK variation

Consider the zero percent reduction results from Tables A.4, case (1,1,2) and A.2, case (1,2,2). That is, compare (for node set 1, weight set 2) the two

PK sets. Note that the difficulty values are smaller for PK set 2, as is expected. Because of the smaller difficulty for PK set 2, the route selected to Target 25 is longer by over one AGU than for PK set 1. This is because weight set 2 weights difficulty 1.0, and hence the least difficult route is chosen, with no regard for distance or target priority. Target 21 is selected for PK set 1 and target 25 is selected for PK set 2.

b. Shortest route comparison

When weight set (1,0,0) is specified, the shortest distance route is selected, with no consideration of difficulty or target priority. Tables A.3, case (1,1,1) and A.9, case (2,1,1) show that target 21 is always selected for both node sets, since the distance to target 21 is 4.0 AGU.

c. Least difficulty comparison

When weight set (0,1,0) is selected, no consideration is given to distance or target priority in the selection of a target or route. Note from Table A.4, case (1,1,2), that target 21 is selected for node set 1 until the percent reduction reaches 50 %. At this point the difficulty of routes to all targets has been reduced to 0.20, and hence the model shows indifference between the three targets. For node set 2 given in Table A.10, case (2,1,2), some interesting results occur. Note the extremely long route taken to target 21 in order to minimize difficulty. Until 50 % reduction is reached, the model is indifferent between targets 23 and 25. At 50 % reduction, the radii of all air defense sites have been reduced to zero, thus the model is indifferent to all targets.

In sections C.2 and C.3 which follow, several observations from results given in the tables and figures are presented. These by no means represent a total analysis of all combinations of factors, but are provided to give the reader insights into the capabilities of the model package developed for this thesis.

2. Effects of air defense lethal radii reductions

First, consider Table A.5, case (1,1,3) and Figure B.1, the equal weight set. At zero percent reduction, note that target 23 has the most difficult route, and that the model is indifferent between targets 21 and 25 (difference is less than 0.01), with a CV value of 0.65. At 10 % reduction, the difficulty to target 21 reduces substantially (3.24 to 2.32) because of the reduction in ground node 5 in Node set 1 (Figure 8), and hence target 21 is selected with a CV value of 0.58. At 40 % reduction, two interesting observations are noted. Target 23 changes to a longer route (from 30 % reduction) in order to get a less difficult route. Because distance and difficulty are equally weighted, the reduction of difficulty from 1.92 to 0.64 more than compensates for the increase in distance from 4.83 to 5.41. Thus, at 40 % reduction the model is indifferent between targets 21 and 23. At 60 % reduction, all difficulties are getting small, thus the trade-off is essentially between distance and target priority, and all targets are equally desirable. At 70 % reduction and above, however, target priority begins to dominate, and hence target 25 is selected.

Next, consider case (2,1,3) shown in Table A.11 and Figure B.13 which is the equal weight set for node set 2. Target 25 is uniquely the best choice except at 40 % and 50 % reduction. For 30 % reduction, target 25 has a distance of 6.24 and difficulty of 0.57, while target 23 has a distance of 4.83 and difficulty of 0.83. The higher priority for target 25 causes it to be selected over target 23. At 40 % reduction, target 25 has a shorter route distance, 5.66, and higher difficulty, 0.99, while target 23 has a different route but the same distance as before and a smaller difficulty of 0.59 when compared to the 30 % reduction case. The CV value for target 25 increased slightly from 30 % reduction, while it decreased for target 23, making these two targets essentially equal. At 60 % and above reduction level, the priority of target 25 again dominates and causes it to be selected.

Now, consider weight set 6 (0.25,0.25,0.50) for node sets 1 and 2 (see Tables A.8 and A.14; Figures B.4 and B.8). Note that target priority dominates, no matter which level of reduction is considered. The differences between the three targets are large, especially for node set 2, which leads to an important observation. The **magnitude** of the differences in target priority must be considered when selecting the weight to assign to target priority in order to achieve the desired results. This will likely require experimenting with various weight combinations for the actual node set being used.

For example, considering cases (2,1,5) and (2,1,6) shown in Figures B.7 and B.8, respectively, target 25 is always selected. In fact for node set 2 and weight sets 5 and 6, the target whose ratio of target priority to other targets is greater than 1.33 will be selected. This observation obviously changes for different node and weight sets.

3. Effects of Weight Sets

Considering node set 2 (Figures B.9 - B.14 and Tables A.11 - A.14) target 25 is selected in most of the cases. For 0 % and 20 % air defense lethal radii reductions (Figures B.9 and B.10) the only case for which target 25 is not selected is for weight set

4 (0.50,0.25,0.25), in which case target 23 is selected. For 40 % reduction (Figure B.11) target 23 is selected for weight sets 3 and 4, but the difference between targets 23 and 25 for weight set 3 is very small (within 0.01). The first time that target 21 becomes one of the choices for weight set 4 is at 60 % reduction (Figure 20) in which targets 23 and 21 are within 0.01 in **CV** value. Target 21 is slightly preferred at 80 % reduction for weight set 4, because the effect of difficulty becomes very small and the trade-off between distance and priority makes target 21 the best choice. The other major reason for that result is because weight set 4 gives distance the largest weight. At 100 % reduction, difficulty is zero for all routes, and the combined values for weighted distance and priority select target 21, again because distance is weighted twice that of priority.

The analyses presented above were selected to illustrate the flexibility and multi-dimensional nature of the three models. Suggestions for further enhancements to the existing models are given in the next chapter.

VI. SUMMARY AND FUTURE RESEARCH AREAS

Three models have been developed to provide the air operations planner with a method for simultaneous consideration of air base and target location, target priority, distance to target area, and difficulty of the routes arising from various air defense threats. These models, when utilized as a single package, provide the optimal route to a target for various escort aircraft capabilities.

These models, although designed for implementation in FTLM, may be equally useful in a stand-alone mode or in concert with other models of military conflict. This package represents a unique capability which, to the author's knowledge, does not currently exist.

Because this thesis represents the initial research and implementation of a dynamic air planning algorithm, several areas for refinement and enhancement of the current package exist. First, the air reconnaissance mission selection process must be refined, particularly in the specification of area priorities for gathering intelligence. In that regard, the current package needs to be expanded to allow for multiple destination areas during the same flight mission.

Secondly, the prioritization of targets for combat engagement must be developed, based on research results from Air Force Institute of Technology. Thirdly, the notion of percent reduction in air defense threat in Model III must be related to specific characteristics of various escort aircraft types. Also, that percent reduction currently reduces only the perceived lethal radius of each air defense site. Enhancements are required to consider escort jammers against air defense radars, in addition to lethal suppression. Finally, the counter-air threat, even though covered conceptually in the current package, needs additional research related to the various types and activities of counter-air threats.

This document represents an initial attempt to provide a dynamic tool for planning air operations. The author hopes that other individuals will be motivated to continue research in this very important area.

APPENDIX A

RESULT (TABLES) OF DYNAMIC TARGET SELECTION MODEL

This appendix contains data tables for various cases of node, PK, and weight sets. Selected outputs of node set 1 for PK sets 1 and 2; weight sets 1-6, are given in Tables A.1-A.8. For node set 2, PK set 2 associated with weight sets 1-6 are given in Tables A.9-A.14. Notation used for the tables is as follows:

- W_1 is the weight of travel distance.
- W_2 is the weight of difficulty.
- W_3 is the weight of target priority.
- $W_1 + W_2 + W_3 = 1$
- W_1^* is the weight of travel distance used in the Air Route Selection Model (Chapter IV).
- W_2^* is the weight of difficulty used in Chapter IV
- $W_1^* + W_2^* = 1$
- ACT is the actual value of the parameter.
- NOR is the normalized value of the parameter.

All weight values are given at the top of each table. When the difference between the smallest combined values is less than 0.01, these targets are considered equally desirable.

TABLE A.1 : NODE SET 1, PK SET 2 , WEIGHT SET 1

```
FOR W1  =  1.00   W2  =  0.00   W3  =  0.00

    W1* =  1.00   W2* =  0.00



FOR  0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71      3.16  0.66    40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85      3.84  0.80    60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00      4.80  1.00    80.00   1.00

  W1      W2      W3       21      23      25     TARGET SELECTED COMBINED VALUE

 1.00     0.00    0.00  0.707  0.853  0.999         21                0.71


FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71      2.25  0.47    40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85      3.11  0.65    60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00      4.15  0.86    80.00   1.00

  W1      W2      W3       21      23      25     TARGET SELECTED COMBINED VALUE

 1.00     0.00    0.00  0.707  0.853  0.999         21                0.71


FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71      1.50  0.31    40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85      2.47  0.51    60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00      3.46  0.72    80.00   1.00

  W1      W2      W3       21      23      25     TARGET SELECTED COMBINED VALUE

 1.00     0.00    0.00  0.707  0.853  0.999         21                0.71


FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.
```

```
                                           DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                        ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.89   0.19    40.00   0.50

  23   1- 6-11-17-23                     4.83    0.85      1.89   0.39    60.00   0.75

  25   1- 7-13-19-25                     5.66    1.00      2.74   0.57    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 1.00    0.00    0.00   0.707   0.853   0.999          21               0.71

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                        ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.43   0.09    40.00   0.50

  23   1- 6-11-17-23                     4.83    0.85      1.43   0.30    60.00   0.75

  25   1- 7-13-19-25                     5.66    1.00      2.05   0.43    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 1.00    0.00    0.00   0.707   0.853   0.999          21               0.71

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                        ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.18   0.04    40.00   0.50

  23   1- 6-11-17-23                     4.83    0.85      0.97   0.20    60.00   0.75

  25   1- 7-13-19-25                     5.66    1.00      1.39   0.29    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 1.00    0.00    0.00   0.707   0.853   0.999          21               0.71

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                        ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.11   0.02    40.00   0.50

  23   1- 6-11-17-23                     4.83    0.85      0.61   0.13    60.00   0.75

  25   1- 7-13-19-25                     5.66    1.00      0.89   0.19    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 1.00    0.00    0.00   0.707   0.853   0.999          21               0.71

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                        ACT     NOR      ACT     NOR     ACT     NOR
```

```
  21   1- 6-11-16-21              4.00   0.71     0.06  0.01    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85     0.34  0.07    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00     0.50  0.10    80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999         21               0.71

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT    NOR      ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71     0.03  0.01    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85     0.16  0.03    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00     0.23  0.05    80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999         21               0.71

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT    NOR      ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71     0.01  0.00    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85     0.04  0.01    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00     0.05  0.01    80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999         21               0.71

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT    NOR      ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71     0.00  0.00    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85     0.00  0.00    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00     0.00  0.00    80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999         21               0.71
```

TABLE A.2 : NODE SET 1, PK SET 2 , WEIGHT SET 2

FOR W_1 = 0.00 W_2 = 1.00 W_3 = 0.00

W_1^* = 0.00 W_2^* = 1.00

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	3.16	0.82	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.84	1.00	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	2.86	0.74	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.823	1.000	0.745	25	0.75

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	2.25	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.11	0.81	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	2.28	0.59	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.586	0.810	0.594	21/25	0.59

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	1.50	0.39	40.00	0.50
23	1- 2- 3- 4-10-15-20-25-24-23	9.41	1.27	2.31	0.60	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	1.77	0.46	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.391	0.602	0.461	21	0.39

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                    DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21                4.00    0.54     0.89   0.23    40.00   0.50

  23  1- 6-11-16-22-23             5.41    0.73     1.43   0.37    60.00   0.75

  25  1- 2- 3- 9-15-20-25          6.83    0.92     1.35   0.35    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.232  0.372  0.352         21               0.23

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                    DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21                4.00    0.54     0.43   0.11    40.00   0.50

  23  1- 6-11-16-22-23             5.41    0.73     0.61   0.16    60.00   0.75

  25  1- 6-11-16-22-23-24-25       7.41    1.00     0.61   0.16    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.112  0.159  0.159         21               0.11

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                    DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21                4.00    0.54     0.18   0.05    40.00   0.50

  23  1- 6-11-16-22-23             5.41    0.73     0.18   0.05    60.00   0.75

  25  1- 6-11-16-22-23-24-25       7.41    1.00     0.18   0.05    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.047  0.047  0.047         21/23/25         0.05

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                    DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21                4.00    0.54     0.11   0.03    40.00   0.50

  23  1- 6-11-16-22-23             5.41    0.73     0.11   0.03    60.00   0.75

  25  1- 6-11-16-22-23-24-25       7.41    1.00     0.11   0.03    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.029  0.029  0.029         21/23/25         0.03

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                    DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR
```

```
  21   1- 6-11-16-21               4.00    0.54      0.06  0.02     40.00  0.50

  23   1- 6-11-16-22-23            5.41    0.73      0.06  0.02     60.00  0.75

  25   1- 6-11-16-22-23-24-25      7.41    1.00      0.06  0.02     80.00  1.00

  W1      W2      W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.016   0.016   0.016          21/23/25          0.02

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT    NOR      ACT     NOR

  21   1- 6-11-16-21               4.00    0.54      0.03  0.01     40.00  0.50

  23   1- 6-11-16-22-23            5.41    0.73      0.03  0.01     60.00  0.75

  25   1- 6-11-16-22-23-24-25      7.41    1.00      0.03  0.01     80.00  1.00

  W1      W2      W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.008   0.008   0.008          21/23/25          0.01

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT    NOR      ACT     NOR

  21   1- 7-11-16-21               4.83    0.65      0.01  0.00     40.00  0.50

  23   1- 6-11-16-22-23            5.41    0.73      0.01  0.00     60.00  0.75

  25   1- 6-11-16-22-23-24-25      7.41    1.00      0.01  0.00     80.00  1.00

  W1      W2      W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.003   0.003   0.003          21/23/25          0.00

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT    NOR      ACT     NOR

  21   1- 6-11-16-21               4.00    0.54      0.00  0.00     40.00  0.50

  23   1- 6-12-17-23               4.83    0.65      0.00  0.00     60.00  0.75

  25   1- 6-12-17-23-24-25         6.83    0.92      0.00  0.00     80.00  1.00

  W1      W2      W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.000   0.000   0.000          21/23/25          0.00
```

TABLE A.3 : NODE SET 1, PK SET 1 , WEIGHT SET 1

FOR W_1 = 1.00 W_2 = 0.00 W_3 = 0.00

W_1^* = 1.00 W_2^* = 0.00

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	3.24	0.60	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	3.92	0.73	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	5.39	1.00	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	2.32	0.43	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	3.18	0.59	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	4.65	0.86	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	1.55	0.29	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	2.52	0.47	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	3.89	0.72	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                  DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT    NOR    ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71    0.92  0.17    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85    1.92  0.36    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00    3.08  0.57    80.00  1.00

  W1     W2     W3     21     23     25    TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21               0.71

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT    NOR    ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71    0.46  0.09    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85    1.46  0.27    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00    2.32  0.43    80.00  1.00

  W1     W2     W3     21     23     25    TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21               0.71

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT    NOR    ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71    0.20  0.04    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85    0.99  0.18    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00    1.57  0.29    80.00  1.00

  W1     W2     W3     21     23     25    TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21               0.71

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT    NOR    ACT    NOR     ACT    NOR

  21   1- 6-11-16-21              4.00   0.71    0.13  0.02    40.00  0.50

  23   1- 6-11-17-23              4.83   0.85    0.63  0.12    60.00  0.75

  25   1- 7-13-19-25              5.66   1.00    1.00  0.19    80.00  1.00

  W1     W2     W3     21     23     25    TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21               0.71

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT    NOR    ACT    NOR     ACT    NOR
```

```
  21  1- 6-11-16-21              4.00   0.71      0.07  0.01    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.35  0.06    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.56  0.10    80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707   0.853   0.999         21                0.71

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY      PRIORITY
TARGET      ROUTE                ACT     NOR      ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.71      0.03  0.01    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.16  0.03    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.25  0.05    80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707   0.853   0.999         21                0.71

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY      PRIORITY
TARGET      ROUTE                ACT     NOR      ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.71      0.01  0.00    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.04  0.01    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.07  0.01    80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707   0.853   0.999         21                0.71

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY      PRIORITY
TARGET      ROUTE                ACT     NOR      ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.71      0.00  0.00    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.00  0.00    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.00  0.00    80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707   0.853   0.999         21                0.71
```

TABLE A.4 : NODE SET 1, PK SET 1 , WEIGHT SET 2

FOR W_1 = 0.00 W_2 = 1.00 W_3 = 0.00

W_1* = 0.00 W_2* = 1.00

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	3.24	0.83	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.92	1.00	60.00	0.75
25	1- 6-12-18-24-25	6.24	0.84	3.70	0.94	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.827	1.000	0.944	21	0.83

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	2.32	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.18	0.81	60.00	0.75
25	1- 6-12-18-24-25	6.24	0.84	3.06	0.78	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.592	0.811	0.781	21	0.59

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	1.55	0.40	40.00	0.50
23	1- 6-11-16-22-23	5.41	0.73	2.50	0.64	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	2.53	0.65	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.395	0.638	0.645	21	0.40

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                      DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                     ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54      0.92   0.23    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73      1.46   0.37    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00      1.46   0.37    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00     1.00    0.00   0.235   0.372   0.372         21               0.24

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                     ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54      0.46   0.12    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73      0.64   0.16    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00      0.64   0.16    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00     1.00    0.00   0.117   0.163   0.163         21               0.12

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                     ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54      0.20   0.05    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73      0.20   0.05    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00      0.20   0.05    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00     1.00    0.00   0.051   0.051   0.051       21/23/25           0.05

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                     ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54      0.13   0.03    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73      0.13   0.03    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00      0.13   0.03    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00     1.00    0.00   0.033   0.033   0.033       21/23/25           0.03

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                     ACT     NOR      ACT     NOR     ACT     NOR
```

```
  21  1- 6-11-16-21              4.00   0.54     0.07  0.02    40.00  0.50

  23  1- 6-11-16-22-23           5.41   0.73     0.07  0.02    60.00  0.75

  25  1- 6-11-16-22-23-24-25     7.41   1.00     0.07  0.02    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.018  0.018  0.018        21/23/25          0.02

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT     NOR      ACT     NOR      ACT     NOR

  21  1- 6-11-16-21              4.00   0.54     0.03  0.01    40.00  0.50

  23  1- 6-11-16-22-23           5.41   0.73     0.03  0.01    60.00  0.75

  25  1- 6-11-16-22-23-24-25     7.41   1.00     0.03  0.01    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.008  0.008  0.008        21/23/25          0.01

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT     NOR      ACT     NOR      ACT     NOR

  21  1- 6-11-16-21              4.00   0.54     0.01  0.00    40.00  0.50

  23  1- 6-11-16-22-23           5.41   0.73     0.01  0.00    60.00  0.75

  25  1- 6-11-16-22-23-24-25     7.41   1.00     0.01  0.00    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.003  0.003  0.003        21/23/25          0.00

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT     NOR      ACT     NOR      ACT     NOR

  21  1- 6-11-16-21              4.00   0.54     0.00  0.00    40.00  0.50

  23  1- 6-12-17-23              4.83   0.65     0.00  0.00    60.00  0.75

  25  1- 6-12-17-23-24-25        6.83   0.92     0.00  0.00    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00    0.00  0.000  0.000  0.000        21/23/25          0.00
```

TABLE A.5 : NODE SET 1, PK SET 1 , WEIGHT SET 3

FOR W_1 = 0.33 W_2 = 0.33 W_3 = 0.33

W_1^* = 0.50 W_2^* = 0.50

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	3.24	0.83	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.92	1.00	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.70	0.94	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.655	0.674	0.647	25/21	0.65

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.32	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.18	0.81	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.06	0.78	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.577	0.611	0.593	21	0.58

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	1.55	0.40	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	2.52	0.64	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	2.62	0.67	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.512	0.555	0.556	21	0.51

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                        DISTANCE      DIFFICULTY     PRIORITY
TARGET      ROUTE                     ACT     NOR     ACT    NOR    ACT    NOR

  21   1- 6-11-16-21                  4.00    0.64     0.92  0.23   40.00  0.50

  23   1- 6-11-17-23                  4.83    0.77     1.92  0.49   60.00  0.75

  25   1- 2- 8-14-20-25               6.24    1.00     2.07  0.53   80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.458  0.504  0.509        21              0.46

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE      DIFFICULTY     PRIORITY
TARGET      ROUTE                     ACT     NOR     ACT    NOR    ACT    NOR

  21   1- 6-11-16-21                  4.00    0.64     0.46  0.12   40.00  0.50

  23   1- 6-11-16-22-23               5.41    0.87     0.64  0.16   60.00  0.75

  25   1- 2- 8-14-20-25               6.24    1.00     1.31  0.33   80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.419  0.427  0.444        21/23           0.42

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE      DIFFICULTY     PRIORITY
TARGET      ROUTE                     ACT     NOR     ACT    NOR    ACT    NOR

  21   1- 6-11-16-21                  4.00    0.64     0.20  0.05   40.00  0.50

  23   1- 6-11-16-22-23               5.41    0.87     0.20  0.05   60.00  0.75

  25   1- 7- 8-14-20-25               6.24    1.00     0.79  0.20   80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.397  0.389  0.400        23/21           0.39

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE      DIFFICULTY     PRIORITY
TARGET      ROUTE                     ACT     NOR     ACT    NOR    ACT    NOR

  21   1- 6-11-16-21                  4.00    0.64     0.13  0.03   40.00  0.50

  23   1- 6-11-17-23                  4.83    0.77     0.63  0.16   60.00  0.75

  25   1- 7-13-19-25                  5.66    0.91     1.00  0.26   80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.391  0.394  0.387        25/21/23        0.39

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE      DIFFICULTY     PRIORITY
TARGET      ROUTE                     ACT     NOR     ACT    NOR    ACT    NOR
```

```
  21   1- 6-11-16-21                4.00   0.64      0.07  0.02     40.00  0.50

  23   1- 6-11-17-23                4.83   0.77      0.35  0.09     60.00  0.75

  25   1- 7-13-19-25                5.66   0.91      0.56  0.14     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.33    0.33   0.33  0.386  0.371  0.349        25               0.35

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT    NOR      ACT    NOR      ACT    NOR

  21   1- 6-11-16-21                4.00   0.64      0.03  0.01     40.00  0.50

  23   1- 6-11-17-23                4.83   0.77      0.16  0.04     60.00  0.75

  25   1- 7-13-19-25                5.66   0.91      0.25  0.06     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.33    0.33   0.33  0.383  0.355  0.323        25               0.32

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT    NOR      ACT    NOR      ACT    NOR

  21   1- 6-11-16-21                4.00   0.64      0.01  0.00     40.00  0.50

  23   1- 6-11-17-23                4.83   0.77      0.04  0.01     60.00  0.75

  25   1- 7-13-19-25                5.66   0.91      0.07  0.02     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.33    0.33   0.33  0.381  0.344  0.308        25               0.31

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT    NOR      ACT    NOR      ACT    NOR

  21   1- 6-11-16-21                4.00   0.64      0.00  0.00     40.00  0.50

  23   1- 6-11-17-23                4.83   0.77      0.00  0.00     60.00  0.75

  25   1- 7-13-19-25                5.66   0.91      0.00  0.00     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.33    0.33   0.33  0.380  0.341  0.302        25               0.30
```

TABLE A.6 : NODE SET 1, PK SET 1 , WEIGHT SET 4

FOR W_1 = 0.50 W_2 = 0.25 W_3 = 0.25

W_1^* = 0.67 W_2^* = 0.33

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	3.24	0.83	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.92	1.00	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.70	0.94	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.652	0.699	0.736	21	0.65

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.32	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.18	0.81	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.06	0.78	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.593	0.652	0.695	21	0.59

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	1.55	0.40	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	2.52	0.64	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	2.62	0.67	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.544	0.610	0.667	21	0.54

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                     DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                4.00    0.64     0.92   0.23    40.00   0.50

  23   1- 6-11-17-23                4.83    0.77     1.92   0.49    60.00   0.75

  25   1- 7-13-19-25                5.66    0.91     3.08   0.79    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.504   0.572   0.650         21               0.50

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                4.00    0.64     0.46   0.12    40.00   0.50

  23   1- 6-11-17-23                4.83    0.77     1.46   0.37    60.00   0.75

  25   1- 7-13-19-25                5.66    0.91     2.32   0.59    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.475   0.543   0.601         21               0.48

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                4.00    0.64     0.20   0.05    40.00   0.50

  23   1- 6-11-17-23                4.83    0.77     0.99   0.25    60.00   0.75

  25   1- 7-13-19-25                5.66    0.91     1.57   0.40    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.458   0.513   0.553         21               0.46

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                4.00    0.64     0.13   0.03    40.00   0.50

  23   1- 6-11-17-23                4.83    0.77     0.63   0.16    60.00   0.75

  25   1- 7-13-19-25                5.66    0.91     1.00   0.26    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.454   0.490   0.517         21               0.45

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                   ACT     NOR     ACT     NOR     ACT     NOR
```

```
  21   1- 6-11-16-21               4.00    0.64      0.07  0.02     40.00  0.50

  23   1- 6-11-17-23               4.83    0.77      0.35  0.09     60.00  0.75

  25   1- 7-13-19-25               5.66    0.91      0.56  0.14     80.00  1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.450   0.472   0.489         21                0.45

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21               4.00    0.64      0.03  0.01     40.00  0.50

  23   1- 6-11-17-23               4.83    0.77      0.16  0.04     60.00  0.75

  25   1- 7-13-19-25               5.66    0.91      0.25  0.06     80.00  1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.447   0.460   0.469         21                0.45

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21               4.00    0.64      0.01  0.00     40.00  0.50

  23   1- 6-11-17-23               4.83    0.77      0.04  0.01     60.00  0.75

  25   1- 7-13-19-25               5.66    0.91      0.07  0.02     80.00  1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.446   0.452   0.458         21/23             0.45

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                  ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21               4.00    0.64      0.00  0.00     40.00  0.50

  23   1- 6-11-17-23               4.83    0.77      0.00  0.00     60.00  0.75

  25   1- 7-13-19-25               5.66    0.91      0.00  0.00     80.00  1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.446   0.449   0.453         21/23/25          0.45
```

TABLE A.7 : NODE SET 1, PK SET 1 , WEIGHT SET 5

FOR W_1 = 0.25 W_2 = 0.50 W_3 = 0.25

W_1* = 0.33 W_2* = 0.67

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	3.24	0.83	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.92	1.00	60.00	0.75
25	1- 6-12-18-24-25	6.24	0.84	3.70	0.94	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.673	0.725	0.683	21/25	0.67

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	2.32	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	3.18	0.81	60.00	0.75
25	1- 6-12-18-24-25	6.24	0.84	3.06	0.78	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.556	0.631	0.601	21	0.56

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.54	1.55	0.40	40.00	0.50
23	1- 6-11-17-23	4.83	0.65	2.52	0.64	60.00	0.75
25	1- 6-12-18-24-25	6.24	0.84	2.62	0.67	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.458	0.547	0.545	21	0.46

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                       DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR     ACT      NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54     0.92   0.23    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73     1.46   0.37    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00     1.46   0.37    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25  0.377  0.431  0.436          21               0.38

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                       DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR     ACT      NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54     0.46   0.12    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73     0.64   0.16    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00     0.64   0.16    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25  0.319  0.327  0.332        21/23              0.32

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                       DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR     ACT      NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54     0.20   0.05    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73     0.20   0.05    60.00   0.75

  25   1- 6-11-16-22-23-24-25        7.41    1.00     0.20   0.05    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25  0.285  0.271  0.276        23/25              0.27

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                       DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR     ACT      NOR     ACT     NOR

  21   1- 6-11-16-21                 4.00    0.54     0.13   0.03    40.00   0.50

  23   1- 6-11-16-22-23              5.41    0.73     0.13   0.03    60.00   0.75

  25   1- 7- 8-14-20-25              6.24    0.84     0.51   0.13    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25  0.277  0.262  0.276          23               0.26

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                       DISTANCE       DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR     ACT      NOR     ACT     NOR
```

```
  21  1- 6-11-16-21              4.00   0.54      0.07  0.02     40.00  0.50

  23  1- 6-11-17-23              4.83   0.65      0.35  0.09     60.00  0.75

  25  1- 7-13-19-25              5.66   0.76      0.56  0.14     80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.25   0.50   0.25  0.269  0.270  0.262        25/21/23          0.26

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.54      0.03  0.01     40.00  0.50

  23  1- 6-11-17-23              4.83   0.65      0.16  0.04     60.00  0.75

  25  1- 7-13-19-25              5.66   0.76      0.25  0.06     80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.25   0.50   0.25  0.264  0.246  0.223        25                0.22

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.54      0.01  0.00     40.00  0.50

  23  1- 6-11-17-23              4.83   0.65      0.04  0.01     60.00  0.75

  25  1- 7-13-19-25              5.66   0.76      0.07  0.02     80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.25   0.50   0.25  0.261  0.231  0.200        25                0.20

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET      ROUTE                ACT     NOR     ACT     NOR     ACT     NOR

  21  1- 6-11-16-21              4.00   0.54      0.00  0.00     40.00  0.50

  23  1- 6-11-17-23              4.83   0.65      0.00  0.00     60.00  0.75

  25  1- 7-13-19-25              5.66   0.76      0.00  0.00     80.00  1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.25   0.50   0.25  0.260  0.225  0.191        25                0.19
```

TABLE A.8 : NODE SET 1, PK SET 1 , WEIGHT SET 6

FOR W_1 = 0.25 W_2 = 0.25 W_3 = 0.50

W_1^* = 0.50 W_2^* = 0.50

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	3.24	0.83	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.92	1.00	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.70	0.94	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.617	0.568	0.486	25	0.49

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.32	0.59	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	3.18	0.81	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	3.06	0.78	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.558	0.521	0.445	25	0.45

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	1.55	0.40	40.00	0.50
23	1- 6-11-17-23	4.83	0.77	2.52	0.64	60.00	0.75
25	1- 6-12-18-24-25	6.24	1.00	2.62	0.67	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.509	0.479	0.417	25	0.42

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                        DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64      0.92   0.23    40.00   0.50

  23   1- 6-11-17-23                   4.83    0.77      1.92   0.49    60.00   0.75

  25   1- 2- 8-14-20-25                6.24    1.00      2.07   0.53    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25     0.25    0.50   0.469   0.441   0.382           25               0.38

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64      0.46   0.12    40.00   0.50

  23   1- 6-11-16-22-23                5.41    0.87      0.64   0.16    60.00   0.75

  25   1- 2- 8-14-20-25                6.24    1.00      1.31   0.33    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25     0.25    0.50   0.440   0.383   0.334           25               0.33

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64      0.20   0.05    40.00   0.50

  23   1- 6-11-16-22-23                5.41    0.87      0.20   0.05    60.00   0.75

  25   1- 7- 8-14-20-25                6.24    1.00      0.79   0.20    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25     0.25    0.50   0.423   0.355   0.300           25               0.30

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64      0.13   0.03    40.00   0.50

  23   1- 6-11-17-23                   4.83    0.77      0.63   0.16    60.00   0.75

  25   1- 7-13-19-25                   5.66    0.91      1.00   0.26    80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25     0.25    0.50   0.419   0.359   0.290           25               0.29

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                      ACT     NOR      ACT     NOR     ACT     NOR
```

```
  21   1- 6-11-16-21                4.00    0.64       0.07  0.02     40.00  0.50

  23   1- 6-11-17-23                4.83    0.77       0.35  0.09     60.00  0.75

  25   1- 7-13-19-25                5.66    0.91       0.56  0.14     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.415  0.341  0.262         25               0.26

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                4.00    0.64       0.03  0.01     40.00  0.50

  23   1- 6-11-17-23                4.83    0.77       0.16  0.04     60.00  0.75

  25   1- 7-13-19-25                5.66    0.91       0.25  0.06     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.412  0.329  0.243         25               0.24

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                4.00    0.64       0.01  0.00     40.00  0.50

  23   1- 6-11-17-23                4.83    0.77       0.04  0.01     60.00  0.75

  25   1- 7-13-19-25                5.66    0.91       0.07  0.02     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.411  0.321  0.231         25               0.23

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                      DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                   ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                4.00    0.64       0.00  0.00     40.00  0.50

  23   1- 6-11-17-23                4.83    0.77       0.00  0.00     60.00  0.75

  25   1- 7-13-19-25                5.66    0.91       0.00  0.00     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.410  0.318  0.227         25               0.23
```

TABLE A.9 : NODE SET 2, PK SET 1 , WEIGHT SET 1

FOR W_1 = 1.00 W_2 = 0.00 W_3 = 0.00

W_1^* = 1.00 W_2^* = 0.00

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	3.15	1.00	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	2.84	0.90	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	2.18	0.69	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	2.55	0.81	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	2.34	0.74	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	1.94	0.62	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	2.00	0.63	40.00	0.50
23	1- 6-11-17-23	4.83	0.85	1.87	0.59	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	1.66	0.53	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
1.00	0.00	0.00	0.707	0.853	0.999	21	0.71

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	

```
TARGET      ROUTE                      ACT     NOR       ACT     NOR       ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71       1.53   0.49      40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85       1.46   0.46      60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00       1.34   0.43      80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 1.00     0.00     0.00  0.707   0.853   0.999          21                0.71

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY        PRIORITY
TARGET      ROUTE                      ACT     NOR       ACT     NOR       ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71       1.13   0.36      40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85       1.11   0.35      60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00       0.99   0.31      80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 1.00     0.00     0.00  0.707   0.853   0.999          21                0.71

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY        PRIORITY
TARGET      ROUTE                      ACT     NOR       ACT     NOR       ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71       0.79   0.25      40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85       0.79   0.25      60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00       0.69   0.22      80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 1.00     0.00     0.00  0.707   0.853   0.999          21                0.71

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY        PRIORITY
TARGET      ROUTE                      ACT     NOR       ACT     NOR       ACT     NOR

  21   1- 6-11-16-21                   4.00    0.71       0.51   0.16      40.00   0.50

  23   1- 6-11-17-23                   4.83    0.85       0.51   0.16      60.00   0.75

  25   1- 7-13-19-25                   5.66    1.00       0.44   0.14      80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 1.00     0.00     0.00  0.707   0.853   0.999          21                0.71

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                        DISTANCE        DIFFICULTY        PRIORITY
TARGET      ROUTE                      ACT     NOR       ACT     NOR       ACT     NOR
```

```
  21  1- 6-11-16-21              4.00   0.71      0.28  0.09    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.28  0.09    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.25  0.08    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21              0.71

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET     ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21              4.00   0.71      0.12  0.04    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.12  0.04    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.11  0.03    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21              0.71

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET     ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21              4.00   0.71      0.04  0.01    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.04  0.01    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.03  0.01    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21              0.71

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                  DISTANCE       DIFFICULTY       PRIORITY
TARGET     ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21              4.00   0.71      0.00  0.00    40.00  0.50

  23  1- 6-11-17-23              4.83   0.85      0.00  0.00    60.00  0.75

  25  1- 7-13-19-25              5.66   1.00      0.00  0.00    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 1.00   0.00   0.00  0.707  0.853  0.999        21              0.71
```

TABLE A.10 : NODE SET 2, PK SET 1 , WEIGHT SET 2

FOR W_1 = 0.00 W_2 = 1.00 W_3 = 0.00

W_1^* = 0.00 W_2^* = 1.00

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 2- 3- 4-10-15-20-25-24-23-22-21	11.41	1.00	1.29	1.00	40.00	0.50
23	1- 2- 3- 4-10-15-20-25-24-23	9.41	0.83	0.67	0.52	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	0.65	0.67	0.52	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	1.000	0.519	0.519	23/25	0.52

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 2- 3- 4-10-15-14-18-23-22-21	10.83	0.95	0.78	0.60	40.00	0.50
23	1- 2- 3- 4-10-15-14-18-23	8.83	0.77	0.36	0.28	60.00	0.75
25	1- 2- 3- 4-10-15-14-18-24-25	10.24	0.90	0.36	0.28	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.605	0.279	0.279	23/25	0.28

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 2- 3- 4-10-15-14-18-23-22-21	10.83	0.95	0.37	0.29	40.00	0.50
23	1- 2- 3- 4-10-15-14-18-23	8.83	0.77	0.11	0.09	60.00	0.75
25	1- 2- 3- 4-10-15-14-18-24-25	10.24	0.90	0.11	0.09	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.00	1.00	0.00	0.287	0.085	0.085	23/25	0.09

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

DISTANCE	DIFFICULTY	PRIORITY

```
TARGET     ROUTE                             ACT  NOR     ACT  NOR     ACT  NOR

  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95    0.14 0.11   40.00 0.50

  23  1- 2- 3- 4-10-14-18-23            8.24 0.72    0.00 0.00   60.00  0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90    0.00 0.00   80.00  1.00

  W1     W2     W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.109  0.000  0.000          23/25           0.00

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                             DISTANCE    DIFFICULTY     PRIORITY
TARGET     ROUTE                             ACT  NOR     ACT  NOR      ACT  NOR

  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95    0.04 0.03    40.00 0.50

  23  1- 2- 3- 4-10-14-18-23            8.24 0.72    0.00 0.00    60.00 0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90    0.00 0.00    80.00 1.00

  W1     W2     W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.031  0.000  0.000          23/25           0.00

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                             DISTANCE    DIFFICULTY     PRIORITY
TARGET     ROUTE                             ACT  NOR     ACT  NOR      ACT  NOR

  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95    0.00 0.00    40.00 0.50

  23  1- 2- 3- 4-10-14-18-23            8.24 0.72    0.00 0.00    60.00 0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90    0.00 0.00    80.00 1.00

  W1     W2     W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000          21/23/25        0.00

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                             DISTANCE   DIFFICULTY    PRIORITY
TARGET     ROUTE                             ACT  NOR    ACT  NOR     ACT  NOR

  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95   0.00 0.00   40.00 0.50

  23  1- 2- 3- 4-10-14-18-23            8.24 0.72   0.00 0.00   60.00 0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90   0.00 0.00   80.00 1.00

  W1     W2     W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000          21/23/25        0.00

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                             DISTANCE   DIFFICULTY    PRIORITY
TARGET     ROUTE                             ACT  NOR    ACT  NOR     ACT  NOR
```

```
  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95   0.00 0.00   40.00 0.50

  23  1- 2- 3- 4-10-14-18-23             8.24 0.72   0.00 0.00   60.00 0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90   0.00 0.00   80.00 1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000        21/23/25         0.00

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE   DIFFICULTY    PRIORITY
TARGET      ROUTE                          ACT   NOR   ACT   NOR    ACT   NOR

  21  1- 2- 3- 4-10-15-14-18-23-22-21  10.83 0.95   0.00 0.00   40.00 0.50

  23  1- 2- 3- 4-10-14-18-23             8.24 0.72   0.00 0.00   60.00 0.75

  25  1- 2- 3- 4-10-15-14-18-24-25     10.24 0.90   0.00 0.00   80.00 1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000        21/23/25         0.00

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                              DISTANCE  DIFFICULTY    PRIORITY
TARGET      ROUTE                             ACT   NOR   ACT   NOR   ACT   NOR

  21  1- 2- 3- 4-10-15-14-19-18-23-22-21  11.41  1.00  0.00 0.00  40.00 0.50

  23  1- 2- 3- 4-10-14-19-23                8.24  0.72  0.00 0.00  60.00 0.75

  25  1- 2- 3- 4-10-15-20-25                7.41  0.65  0.00 0.00  80.00 1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000        21/23/25         0.00

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                     DISTANCE        DIFFICULTY      PRIORITY
TARGET      ROUTE                    ACT      NOR      ACT      NOR     ACT      NOR

  21  1- 6-11-16-21                  4.00     0.35      0.00   0.00    40.00   0.50

  23  1- 6-12-17-23                  4.83     0.42      0.00   0.00    60.00   0.75

  25  1- 6-12-17-23-24-25            6.83     0.60      0.00   0.00    80.00   1.00

  W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

 0.00    1.00   0.00  0.000  0.000  0.000        21/23/25         0.00
```

TABLE A.11 : NODE SET 2, PK SET 1 , WEIGHT SET 3

FOR W_1 = 0.33 W_2 = 0.33 W_3 = 0.33

W_1* = 0.50 W_2* = 0.50

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	3.15	1.00	40.00	0.50
23	1- 7-13-18-23	4.83	0.77	1.93	0.61	60.00	0.75
25	1- 7-13-19-25	5.66	0.91	2.18	0.69	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.713	0.545	0.532	25	0.53

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.55	0.81	40.00	0.50
23	1- 6-12-18-23	4.83	0.77	1.63	0.52	60.00	0.75
25	1- 2- 8-14-19-25	6.24	1.00	1.25	0.40	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.650	0.513	0.465	25	0.47

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.00	0.63	40.00	0.50
23	1- 6-12-18-23	4.83	0.77	1.18	0.37	60.00	0.75
25	1- 2- 8-14-19-25	6.24	1.00	0.85	0.27	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.33	0.33	0.33	0.591	0.466	0.423	25	0.42

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                         DISTANCE      DIFFICULTY      PRIORITY
TARGET       ROUTE                     ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64     1.53   0.49    40.00   0.50

  23   1- 6-12-18-23                   4.83    0.77     0.83   0.26    60.00   0.75

  25   1- 2- 8-14-19-25                6.24    1.00     0.57   0.18    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.33    0.33    0.33   0.542   0.429   0.393          25              0.39

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                         DISTANCE      DIFFICULTY      PRIORITY
TARGET       ROUTE                     ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64     1.13   0.36    40.00   0.50

  23   1- 7-12-18-23                   4.83    0.77     0.59   0.19    60.00   0.75

  25   1- 7-13-19-25                   5.66    0.91     0.99   0.31    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.33    0.33    0.33   0.499   0.403   0.407          23/25           0.40

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                         DISTANCE      DIFFICULTY      PRIORITY
TARGET       ROUTE                     ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64     0.79   0.25    40.00   0.50

  23   1- 6-12-18-23                   4.83    0.77     0.40   0.13    60.00   0.75

  25   1- 7-13-19-25                   5.66    0.91     0.69   0.22    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.33    0.33    0.33   0.463   0.383   0.375          25/23           0.38

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                         DISTANCE      DIFFICULTY      PRIORITY
TARGET       ROUTE                     ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21                   4.00    0.64     0.51   0.16    40.00   0.50

  23   1- 7-12-18-23                   4.83    0.77     0.26   0.08    60.00   0.75

  25   1- 7-13-19-25                   5.66    0.91     0.44   0.14    80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.33    0.33    0.33   0.434   0.368   0.348          25              0.35

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                         DISTANCE      DIFFICULTY      PRIORITY
TARGET       ROUTE                     ACT     NOR     ACT     NOR     ACT     NOR
```

```
  21  1- 6-11-16-21            4.00   0.64     0.28  0.09    40.00  0.50

  23  1- 6-12-18-23            4.83   0.77     0.14  0.04    60.00  0.75

  25  1- 7-13-19-25            5.66   0.91     0.25  0.08    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.410  0.356  0.328         25              0.33

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                 DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                ACT    NOR      ACT    NOR     ACT    NOR

  21  1- 6-11-16-21            4.00   0.64     0.12  0.04    40.00  0.50

  23  1- 6-12-18-23            4.83   0.77     0.06  0.02    60.00  0.75

  25  1- 7-13-19-25            5.66   0.91     0.11  0.03    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.393  0.347  0.314         25              0.31

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                 DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                ACT    NOR      ACT    NOR     ACT    NOR

  21  1- 6-11-16-21            4.00   0.64     0.04  0.01    40.00  0.50

  23  1- 6-12-18-23            4.83   0.77     0.02  0.01    60.00  0.75

  25  1- 7-13-19-25            5.66   0.91     0.03  0.01    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.384  0.343  0.305         25              0.31

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                 DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                ACT    NOR      ACT    NOR     ACT    NOR

  21  1- 6-11-16-21            4.00   0.64     0.00  0.00    40.00  0.50

  23  1- 6-11-17-23            4.83   0.77     0.00  0.00    60.00  0.75

  25  1- 7-13-19-25            5.66   0.91     0.00  0.00    80.00  1.00

  W1     W2     W3     21     23     25     TARGET SELECTED COMBINED VALUE

 0.33   0.33   0.33  0.380  0.341  0.302         25              0.30
```

TABLE A.12 : NODE SET 2, PK SET 1 , WEIGHT SET 4

FOR W_1 = 0.50 W_2 = 0.25 W_3 = 0.25

W_1^* = 0.67 W_2^* = 0.33

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE		DIFFICULTY		PRIORITY	
		ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	3.15	1.00	40.00	0.50
23	1- 7-13-18-23	4.83	0.85	1.93	0.61	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	2.18	0.69	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.728	0.642	0.673	23	0.64

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE		DIFFICULTY		PRIORITY	
		ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	2.55	0.81	40.00	0.50
23	1- 7-12-18-23	4.83	0.85	1.63	0.52	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	1.94	0.62	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.681	0.618	0.654	23	0.62

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE		DIFFICULTY		PRIORITY	
		ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.71	2.00	0.63	40.00	0.50
23	1- 6-12-18-23	4.83	0.85	1.18	0.37	60.00	0.75
25	1- 7-13-19-25	5.66	1.00	1.66	0.53	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.50	0.25	0.25	0.637	0.583	0.631	23	0.58

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

```
                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET       ROUTE                       ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      1.53  0.49     40.00  0.50

  23   1- 7-12-18-23                     4.83    0.85      0.83  0.26     60.00  0.75

  25   1- 7-13-19-25                     5.66    1.00      1.34  0.43     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50     0.25    0.25  0.600  0.555  0.606         23                0.56
```

```
FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET       ROUTE                       ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      1.13  0.36     40.00  0.50

  23   1- 6-12-18-23                     4.83    0.85      0.59  0.19     60.00  0.75

  25   1- 7-13-19-25                     5.66    1.00      0.99  0.31     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50     0.25    0.25  0.568  0.536  0.578         23                0.54
```

```
FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET       ROUTE                       ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.79  0.25     40.00  0.50

  23   1- 7-12-18-23                     4.83    0.85      0.40  0.13     60.00  0.75

  25   1- 7-13-19-25                     5.66    1.00      0.69  0.22     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50     0.25    0.25  0.541  0.521  0.554         23                0.52
```

```
FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET       ROUTE                       ACT     NOR      ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                     4.00    0.71      0.51  0.16     40.00  0.50

  23   1- 7-12-18-23                     4.83    0.85      0.26  0.08     60.00  0.75

  25   1- 7-13-19-25                     5.66    1.00      0.44  0.14     80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50     0.25    0.25  0.519  0.510  0.535         23/21             0.51
```

```
FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET       ROUTE                       ACT     NOR      ACT     NOR      ACT     NOR
```

```
  21  1- 6-11-16-21               4.00   0.71     0.28  0.09    40.00  0.50

  23  1- 7-12-18-23               4.83   0.85     0.14  0.04    60.00  0.75

  25  1- 7-13-19-25               5.66   1.00     0.25  0.08    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.501   0.500   0.520         23/21              0.50

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21               4.00   0.71     0.12  0.04    40.00  0.50

  23  1- 7-12-18-23               4.83   0.85     0.06  0.02    60.00  0.75

  25  1- 7-13-19-25               5.66   1.00     0.11  0.03    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.488   0.494   0.508         21/23              0.49

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21               4.00   0.71     0.04  0.01    40.00  0.50

  23  1- 6-12-18-23               4.83   0.85     0.02  0.01    60.00  0.75

  25  1- 7-13-19-25               5.66   1.00     0.03  0.01    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.482   0.491   0.502         21/23              0.48

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                 ACT    NOR      ACT    NOR      ACT    NOR

  21  1- 6-11-16-21               4.00   0.71     0.00  0.00    40.00  0.50

  23  1- 6-11-17-23               4.83   0.85     0.00  0.00    60.00  0.75

  25  1- 7-13-19-25               5.66   1.00     0.00  0.00    80.00  1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.50    0.25    0.25   0.478   0.489   0.500         21                 0.48
```

TABLE A.13 : NODE SET 2, PK SET 1 , WEIGHT SET 5

FOR W_1 = 0.25 W_2 = 0.50 W_3 = 0.25

W_1* = 0.33 W_2* = 0.67

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE ACT	DISTANCE NOR	DIFFICULTY ACT	DIFFICULTY NOR	PRIORITY ACT	PRIORITY NOR
21	1- 6-11-16-21	4.00	0.54	3.15	1.00	40.00	0.50
23	1- 7-13-18-23	4.83	0.65	1.93	0.61	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	0.67	0.21	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.760	0.532	0.356	25	0.36

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE ACT	DISTANCE NOR	DIFFICULTY ACT	DIFFICULTY NOR	PRIORITY ACT	PRIORITY NOR
21	1- 6-11-16-21	4.00	0.54	2.55	0.81	40.00	0.50
23	1- 6-12-18-23	4.83	0.65	1.63	0.52	60.00	0.75
25	1- 2- 3- 4-10-15-20-25	7.41	1.00	0.46	0.15	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.665	0.484	0.323	25	0.32

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

TARGET	ROUTE	DISTANCE ACT	DISTANCE NOR	DIFFICULTY ACT	DIFFICULTY NOR	PRIORITY ACT	PRIORITY NOR
21	1- 6-11-16-21	4.00	0.54	2.00	0.63	40.00	0.50
23	1- 6-12-18-23	4.83	0.65	1.18	0.37	60.00	0.75
25	1- 2- 8-14-20-25	6.24	0.84	0.85	0.27	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.50	0.25	0.577	0.413	0.346	25	0.35

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

DISTANCE DIFFICULTY PRIORITY

```
TARGET      ROUTE                       ACT     NOR       ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                    4.00    0.54       1.53   0.49     40.00   0.50

  23   1- 6-12-18-23                    4.83    0.65       0.83   0.26     60.00   0.75

  25   1- 2- 8-14-19-25                 6.24    0.84       0.57   0.18     80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25   0.503   0.357   0.301          25                0.30

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                       ACT     NOR       ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                    4.00    0.54       1.13   0.36     40.00   0.50

  23   1- 6-12-18-23                    4.83    0.65       0.59   0.19     60.00   0.75

  25   1- 2- 8-14-19-25                 6.24    0.84       0.42   0.13     80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25   0.439   0.319   0.277          25                0.28

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                       ACT     NOR       ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                    4.00    0.54       0.79   0.25     40.00   0.50

  23   1- 6-12-18-23                    4.83    0.65       0.40   0.13     60.00   0.75

  25   1- 2- 8-14-19-25                 6.24    0.84       0.30   0.10     80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25   0.385   0.289   0.258          25                0.26

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                       ACT     NOR       ACT     NOR      ACT     NOR

  21   1- 6-11-16-21                    4.00    0.54       0.51   0.16     40.00   0.50

  23   1- 7-12-18-23                    4.83    0.65       0.26   0.08     60.00   0.75

  25   1- 7-13-19-25                    5.66    0.76       0.44   0.14     80.00   1.00

  W1      W2      W3       21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.50    0.25   0.341   0.267   0.261          25/23             0.26

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                          DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                       ACT     NOR       ACT     NOR      ACT     NOR
```

```
 21  1- 6-11-16-21              4.00    0.54      0.28  0.09    40.00  0.50
 23  1- 6-12-18-23              4.83    0.65      0.14  0.04    60.00  0.75
 25  1- 7-13-19-25              5.66    0.76      0.25  0.08    80.00  1.00

 W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

0.25   0.50   0.25  0.304  0.248  0.231         25              0.23

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT     NOR     ACT     NOR     ACT     NOR
 21  1- 6-11-16-21              4.00    0.54      0.12  0.04    40.00  0.50
 23  1- 6-12-18-23              4.83    0.65      0.06  0.02    60.00  0.75
 25  1- 7-13-19-25              5.66    0.76      0.11  0.03    80.00  1.00

 W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

0.25   0.50   0.25  0.279  0.235  0.208         25              0.21

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT     NOR     ACT     NOR     ACT     NOR
 21  1- 6-11-16-21              4.00    0.54      0.04  0.01    40.00  0.50
 23  1- 7-12-18-23              4.83    0.65      0.02  0.01    60.00  0.75
 25  1- 7-13-19-25              5.66    0.76      0.03  0.01    80.00  1.00

 W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

0.25   0.50   0.25  0.266  0.229  0.196         25              0.20

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE       DIFFICULTY      PRIORITY
TARGET     ROUTE                  ACT     NOR     ACT     NOR     ACT     NOR
 21  1- 6-11-16-21              4.00    0.54      0.00  0.00    40.00  0.50
 23  1- 6-11-17-23              4.83    0.65      0.00  0.00    60.00  0.75
 25  1- 7-13-19-25              5.66    0.76      0.00  0.00    80.00  1.00

 W1     W2     W3      21     23     25     TARGET SELECTED COMBINED VALUE

0.25   0.50   0.25  0.260  0.225  0.191         25              0.19
```

TABLE A.14 : NODE SET 2, PK SET 1 , WEIGHT SET 6

FOR W_1 = 0.25 W_2 = 0.25 W_3 = 0.50

W_1^* = 0.50 W_2^* = 0.50

FOR 0 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	3.15	1.00	40.00	0.50
23	1- 7-13-18-23	4.83	0.77	1.93	0.61	60.00	0.75
25	1- 7-13-19-25	5.66	0.91	2.18	0.69	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.660	0.472	0.400	25	0.40

FOR 10 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.55	0.81	40.00	0.50
23	1- 6-12-18-23	4.83	0.77	1.63	0.52	60.00	0.75
25	1- 2- 8-14-19-25	6.24	1.00	1.25	0.40	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.613	0.448	0.349	25	0.35

FOR 20 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

		DISTANCE		DIFFICULTY		PRIORITY	
TARGET	ROUTE	ACT	NOR	ACT	NOR	ACT	NOR
21	1- 6-11-16-21	4.00	0.64	2.00	0.63	40.00	0.50
23	1- 6-12-18-23	4.83	0.77	1.18	0.37	60.00	0.75
25	1- 2- 8-14-19-25	6.24	1.00	0.85	0.27	80.00	1.00

W_1	W_2	W_3	21	23	25	TARGET SELECTED	COMBINED VALUE
0.25	0.25	0.50	0.569	0.412	0.318	25	0.32

FOR 30 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

DISTANCE DIFFICULTY PRIORITY

```
TARGET      ROUTE                         ACT     NOR       ACT     NOR      ACT     NOR
  21   1- 6-11-16-21                      4.00    0.64      1.53   0.49     40.00   0.50
  23   1- 6-12-18-23                      4.83    0.77      0.83   0.26     60.00   0.75
  25   1- 2- 8-14-19-25                   6.24    1.00      0.57   0.18     80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50   0.532   0.384   0.295         25               0.30

FOR 40 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                         ACT     NOR       ACT     NOR      ACT     NOR
  21   1- 6-11-16-21                      4.00    0.64      1.13   0.36     40.00   0.50
  23   1- 6-12-18-23                      4.83    0.77      0.59   0.19     60.00   0.75
  25   1- 7-13-19-25                      5.66    0.91      0.99   0.31     80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50   0.500   0.365   0.305         25               0.31

FOR 50 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                         ACT     NOR       ACT     NOR      ACT     NOR
  21   1- 6-11-16-21                      4.00    0.64      0.79   0.25     40.00   0.50
  23   1- 6-12-18-23                      4.83    0.77      0.40   0.13     60.00   0.75
  25   1- 7-13-19-25                      5.66    0.91      0.69   0.22     80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50   0.473   0.350   0.281         25               0.28

FOR 60 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                         ACT     NOR       ACT     NOR      ACT     NOR
  21   1- 6-11-16-21                      4.00    0.64      0.51   0.16     40.00   0.50
  23   1- 6-12-18-23                      4.83    0.77      0.26   0.08     60.00   0.75
  25   1- 7-13-19-25                      5.66    0.91      0.44   0.14     80.00   1.00

  W1      W2      W3      21      23      25      TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50   0.451   0.339   0.262         25               0.26

FOR 70 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                           DISTANCE        DIFFICULTY       PRIORITY
TARGET      ROUTE                         ACT     NOR       ACT     NOR      ACT     NOR
```

```
  21   1- 6-11-16-21              4.00    0.64      0.28  0.09     40.00  0.50

  23   1- 6-12-18-23              4.83    0.77      0.14  0.04     60.00  0.75

  25   1- 7-13-19-25              5.66    0.91      0.25  0.08     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.432  0.330  0.246        25              0.25

FOR 80 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21              4.00    0.64      0.12  0.04     40.00  0.50

  23   1- 6-12-18-23              4.83    0.77      0.06  0.02     60.00  0.75

  25   1- 7-13-19-25              5.66    0.91      0.11  0.03     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.420  0.323  0.235        25              0.24

FOR 90 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21              4.00    0.64      0.04  0.01     40.00  0.50

  23   1- 6-12-18-23              4.83    0.77      0.02  0.01     60.00  0.75

  25   1- 7-13-19-25              5.66    0.91      0.03  0.01     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE

 0.25    0.25    0.50  0.413  0.320  0.229        25              0.23

FOR 100 PERCENT REDUCTION IN AIR-DEFENSE LETHAL RADIUS.

                                   DISTANCE      DIFFICULTY      PRIORITY
TARGET      ROUTE                 ACT     NOR     ACT     NOR     ACT     NOR

  21   1- 6-11-16-21              4.00    0.64      0.00  0.00     40.00  0.50

  23   1- 6-11-17-23              4.83    0.77      0.00  0.00     60.00  0.75

  25   1- 7-13-19-25              5.66    0.91      0.00  0.00     80.00  1.00

  W1     W2     W3      21      23      25     TARGET SELECTED COMBINED VALUE
0.25    0.25    0.50  0.410  0.318  0.227        25              0.23
```

APPENDIX B

FIGURES OF RESULTS FOR DYNAMIC ROUTE SELECTION MODEL

The figures given in this appendix are described in Chapter V. Figures B.1 - B.8 show the **CV** (Combined Value) for each target across percent reduction in air defense lethal radii for Node sets 1 and 2, and weight sets 3 - 6. Figure B.9 - B.14 present **CV** for each target across weight sets 3 - 6 for each ten percent increment of reduction in air defense lethal radii.

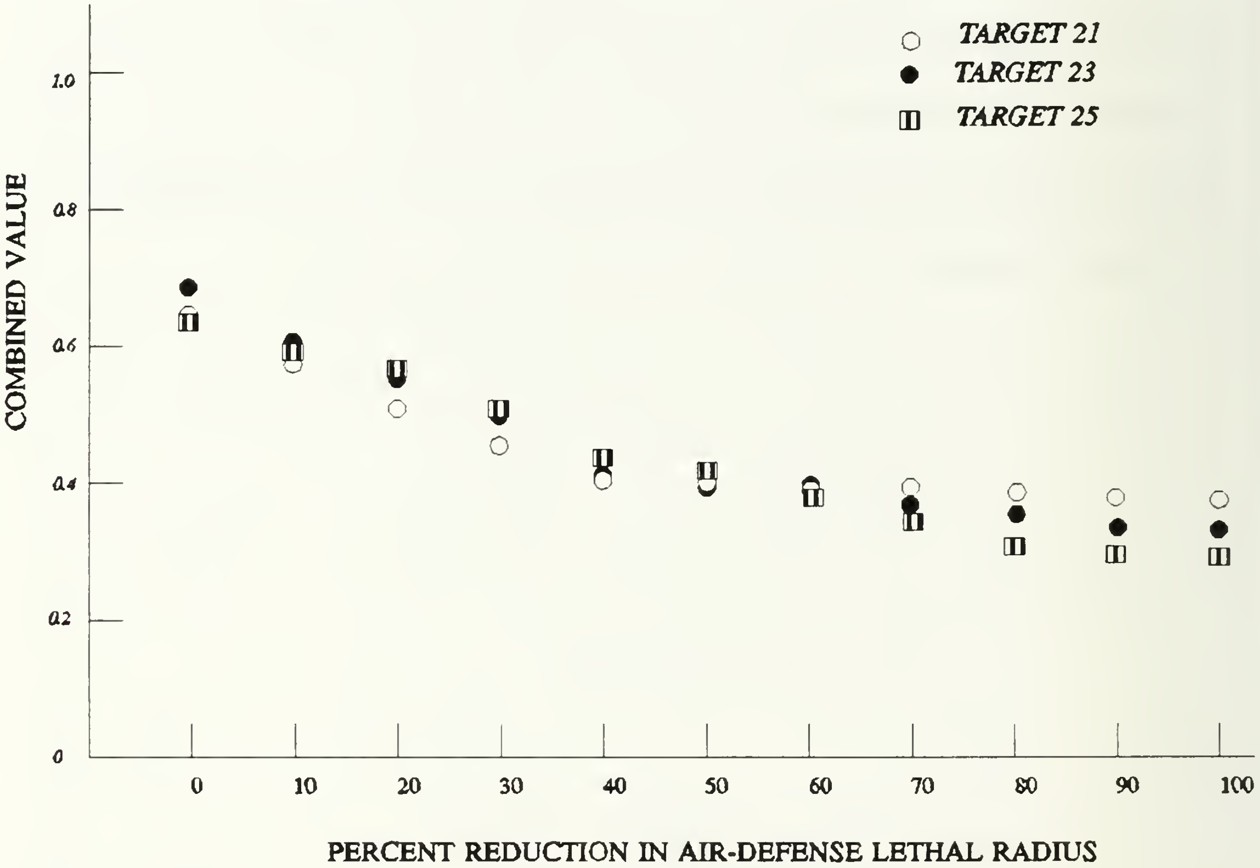

Figure B.1 : Node SET 1 - WEIGHT SET 3 (.33,.33,.33)

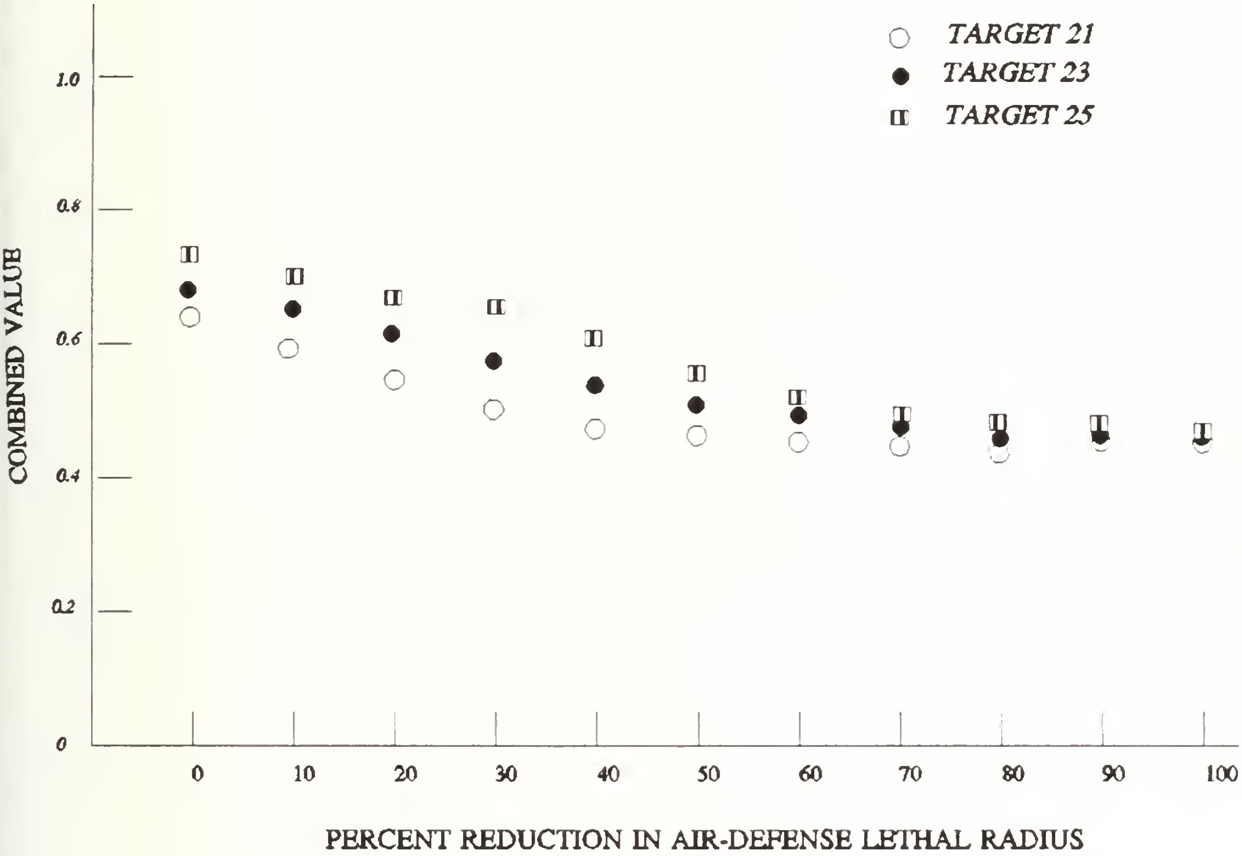

Figure B.2 : Node SET 1 - WEIGHT SET 4 (.50,.25,.25)

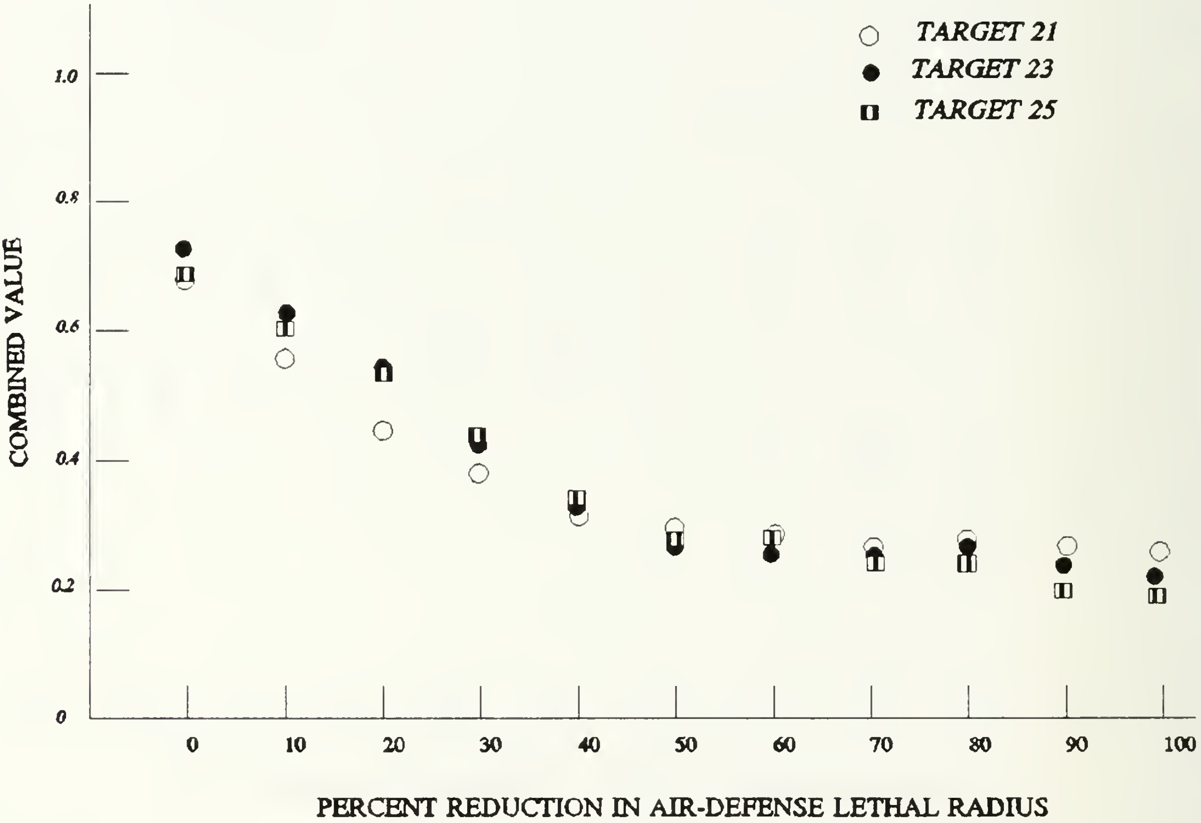

Figure B.3 : Node SET 1 - WEIGHT SET 5 (.25,.50,.25)

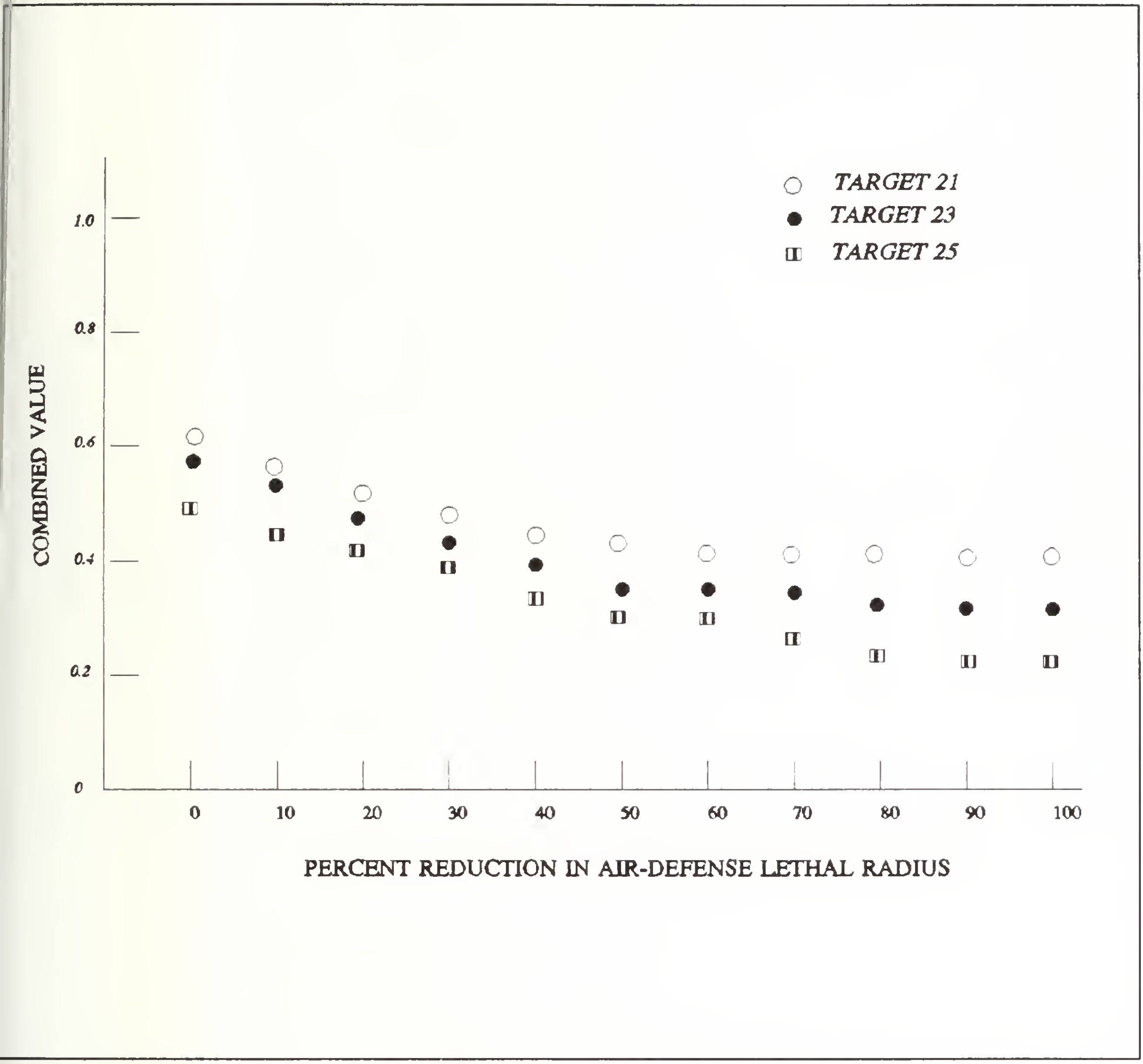

Figure B.4 : Node SET 1 - WEIGHT SET 6 (.25,.25,.50)

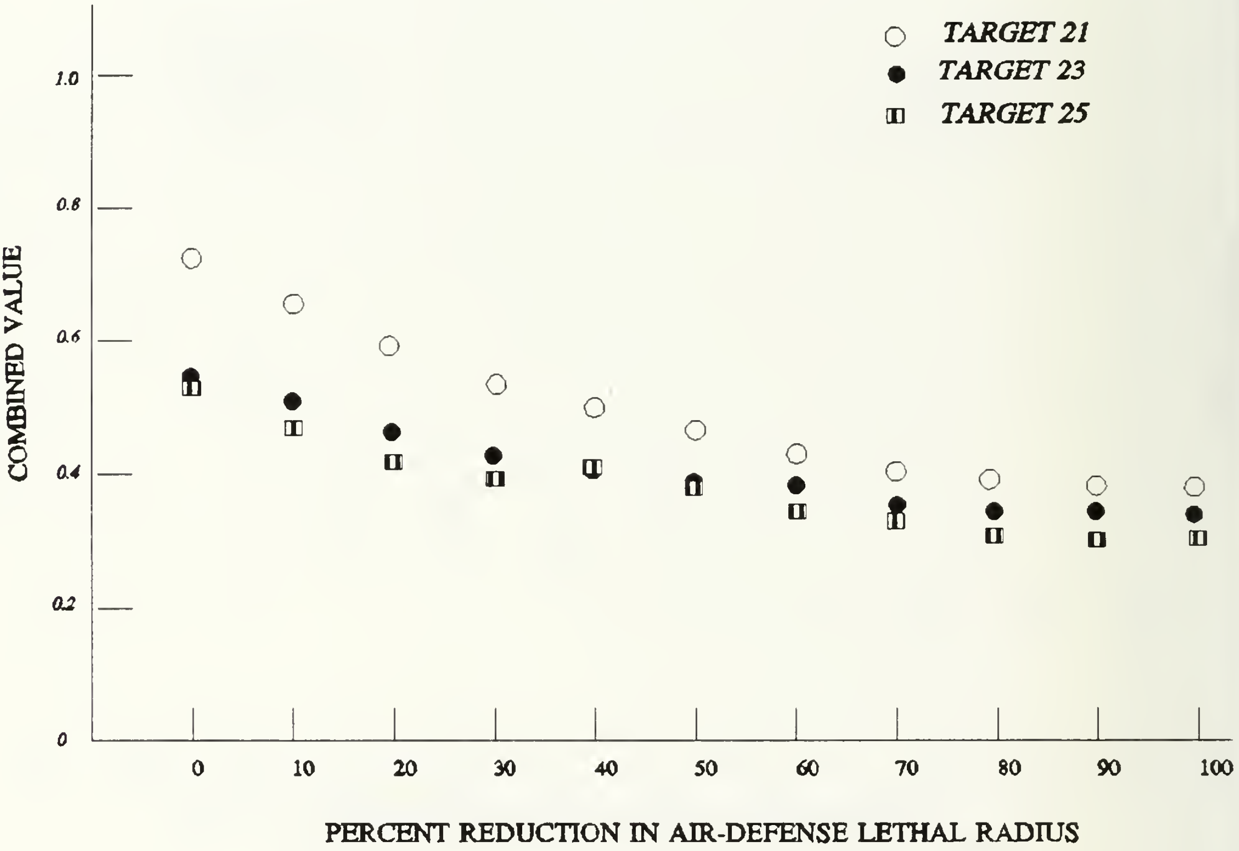

Figure B.5 : Node SET 2 - WEIGHT SET 3 (.33,.33,.33)

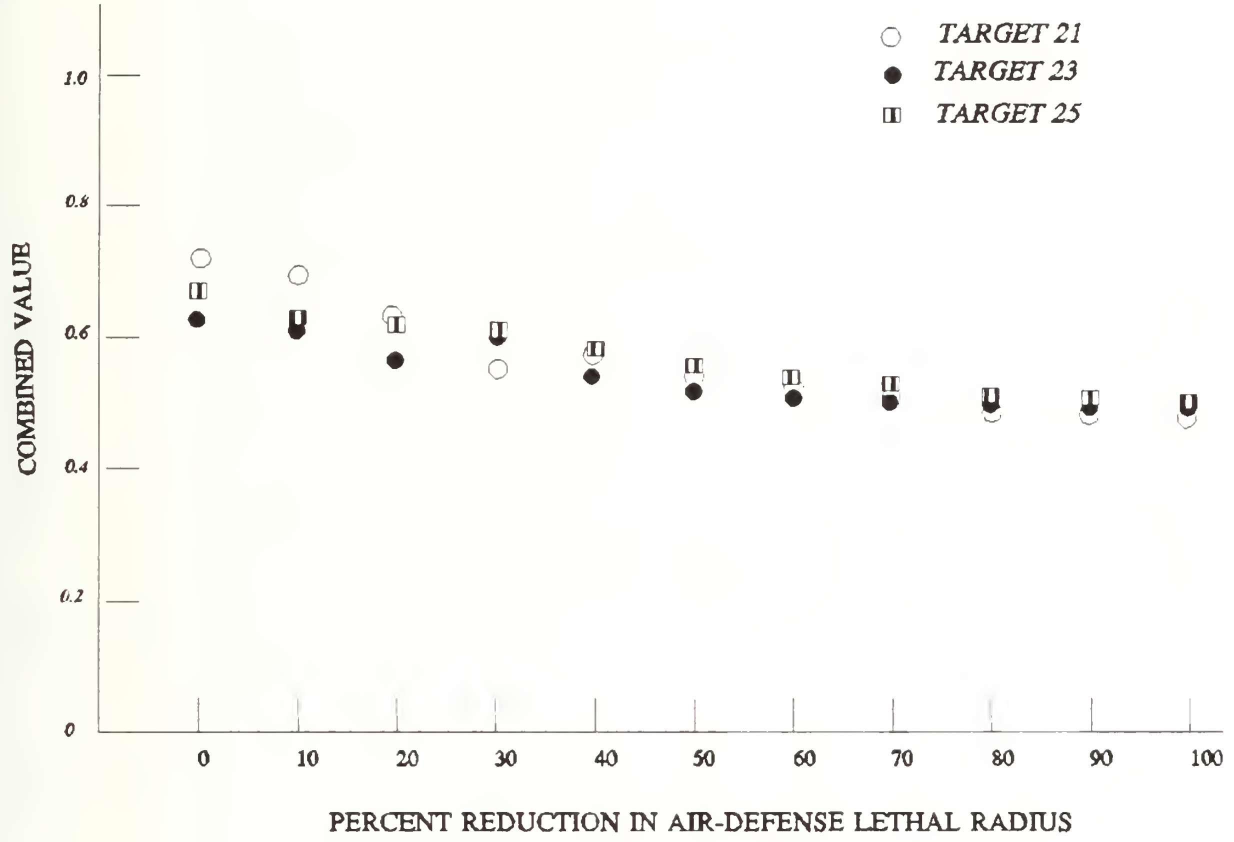

Figure B.6 : Node SET 2 - WEIGHT SET 4 (.50,.25,.25)

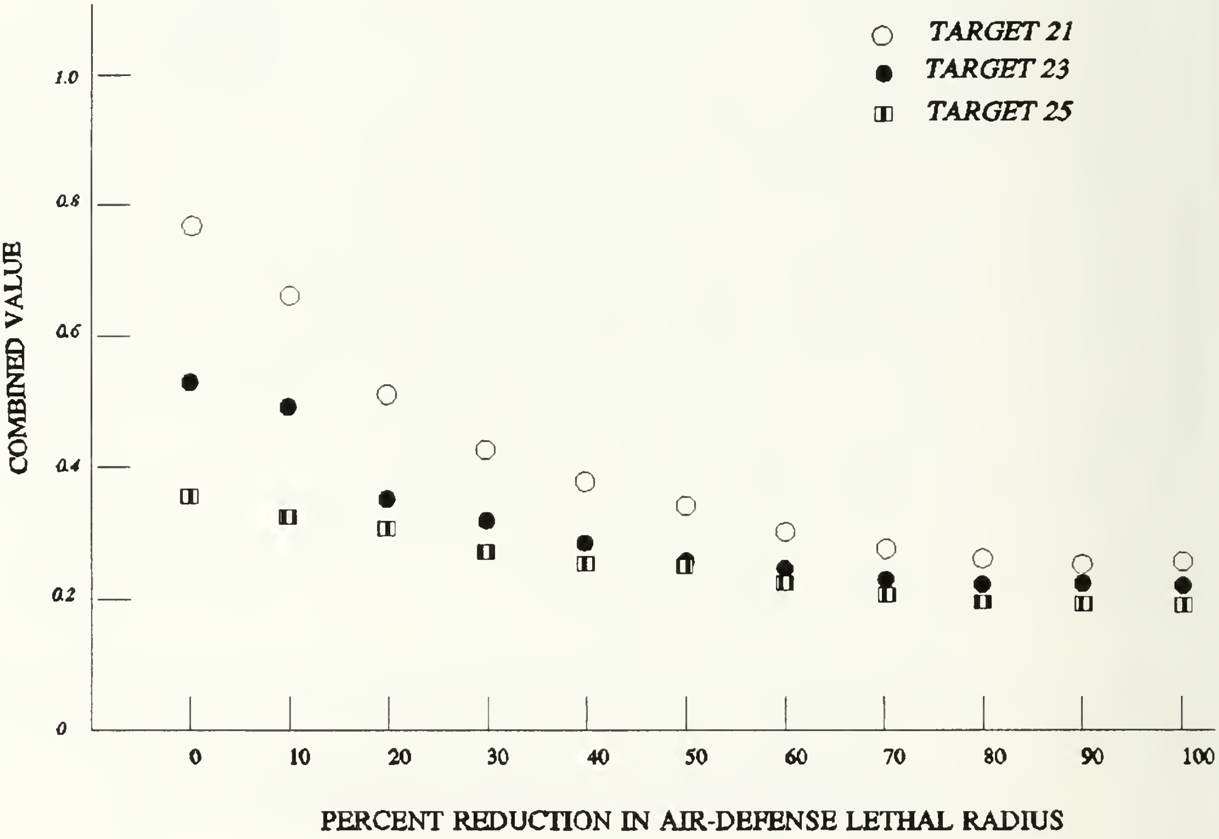

Figure B.7 : Node SET 2 - WEIGHT SET 5 (.25,.50,.25)

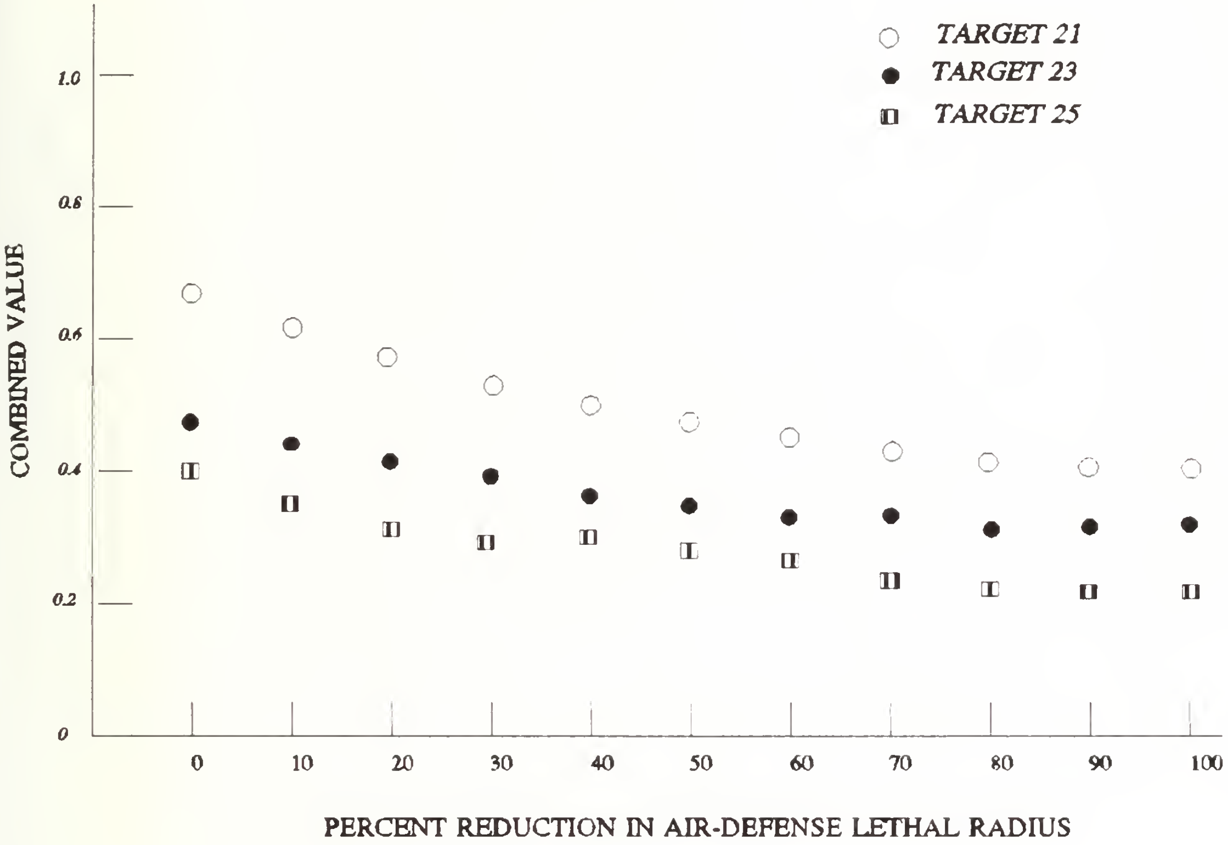

Figure B.8 : Node SET 2 - WEIGHT SET 6 (.25,.25,.50)

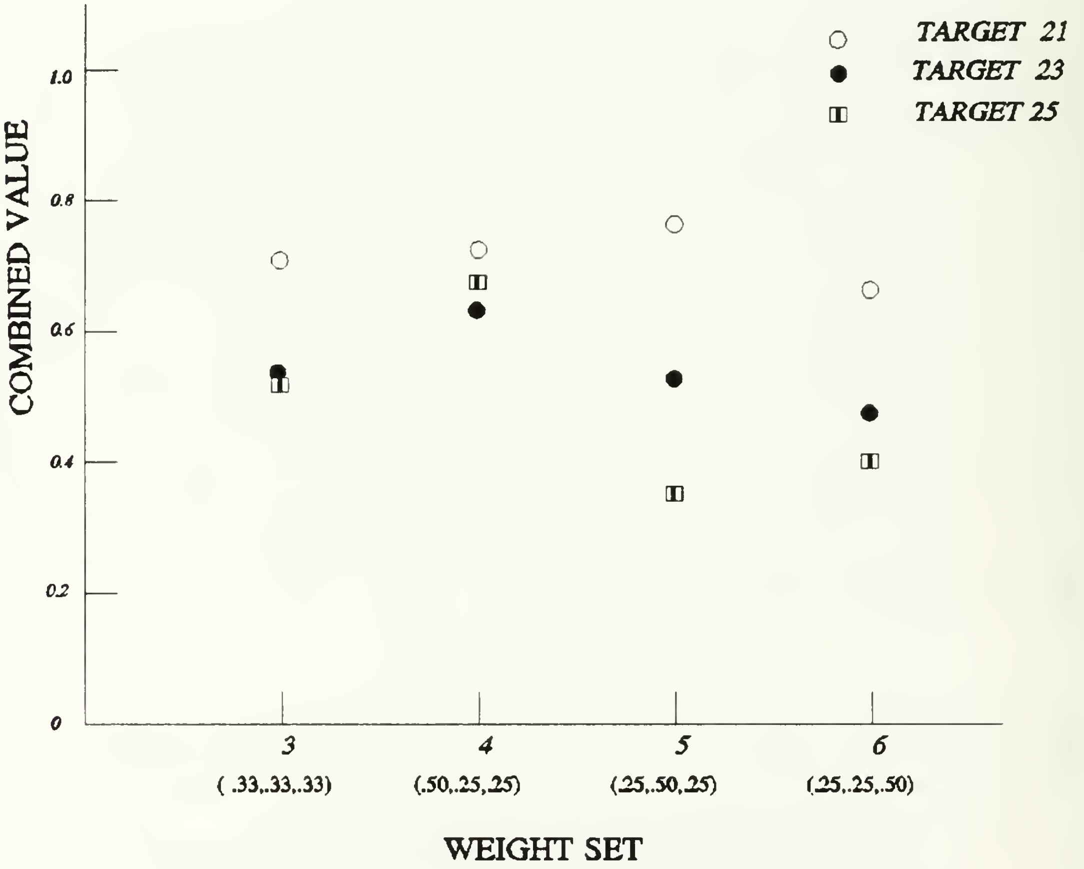

Figure B.9 : 0 Percent Reduction in AD Lethal Radii

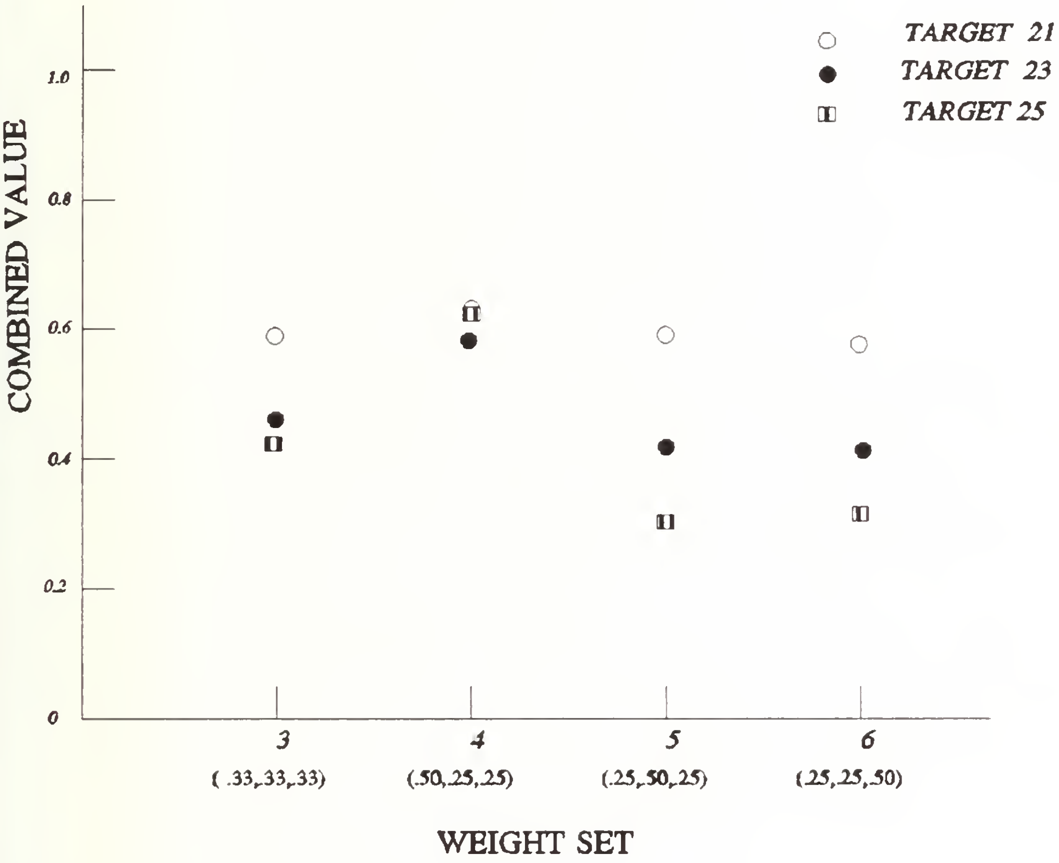

Figure B.10 : 20 Percent Reduction in AD Lethal Radii

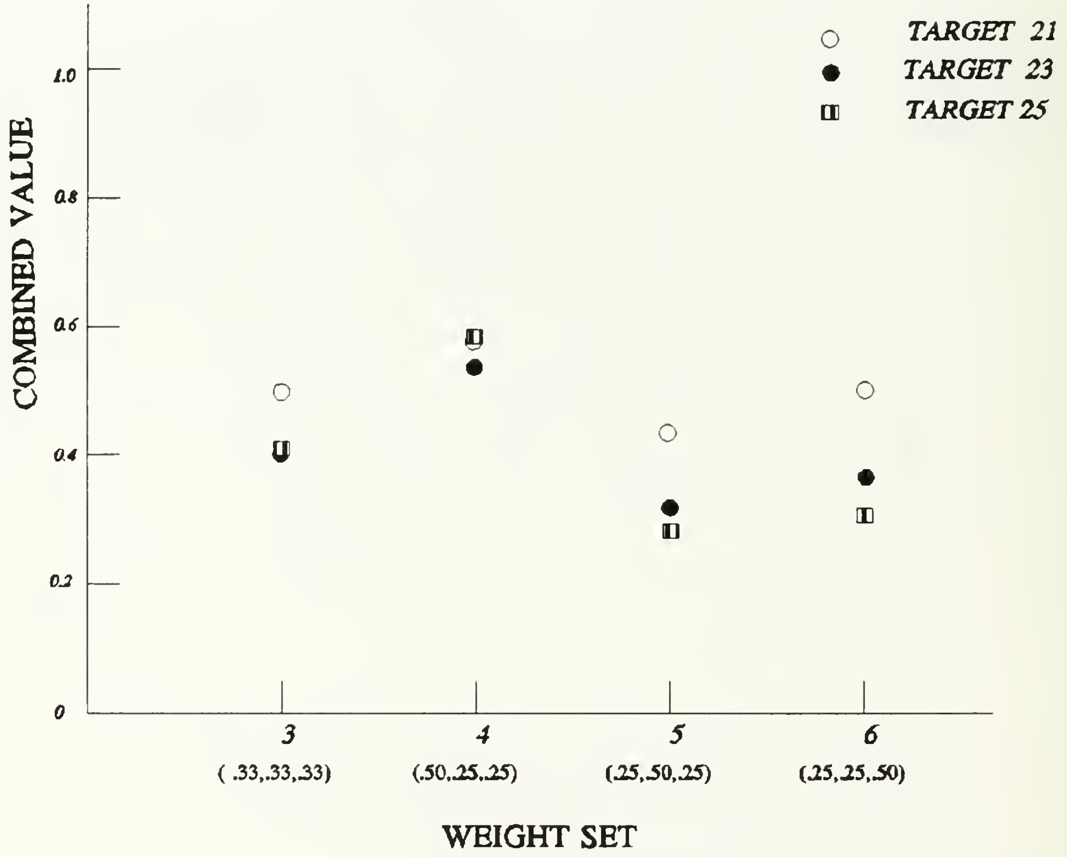

Figure B.11 : 40 Percent Reduction in AD Lethal Radii

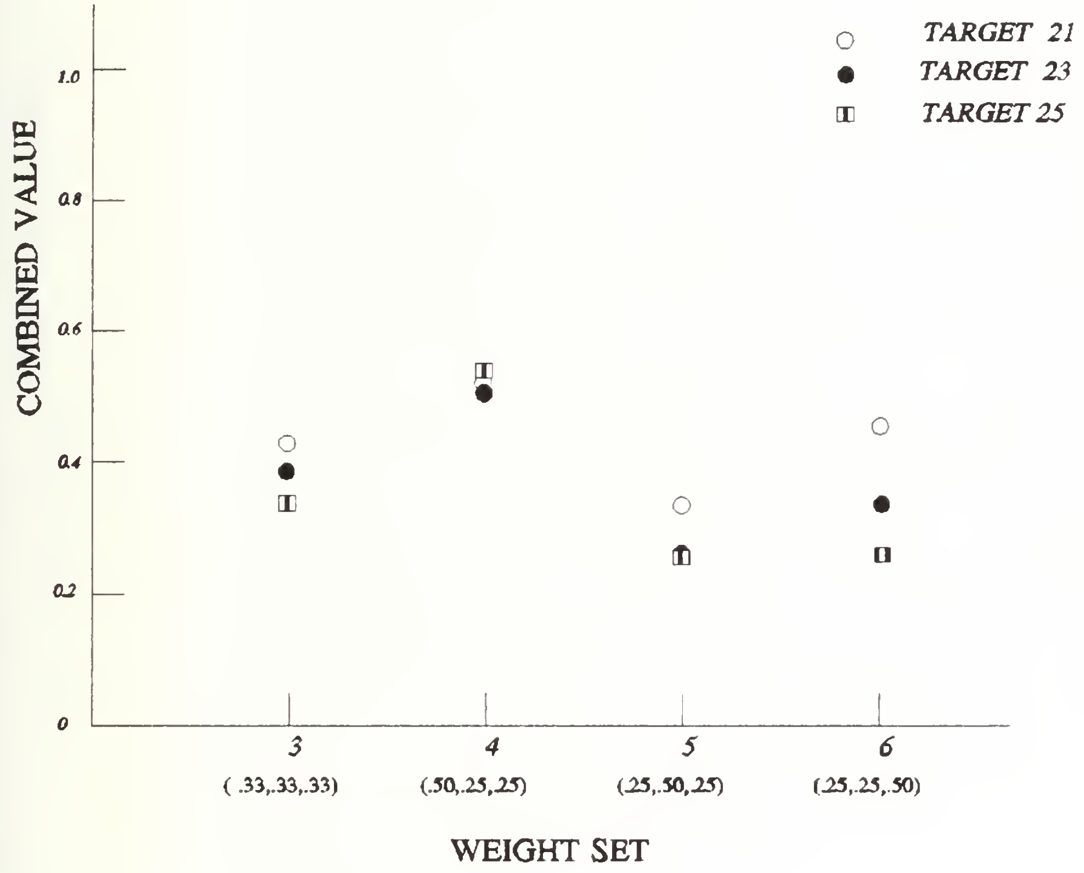

Figure B.12 : 60 Percent Reduction in AD Lethal Radii

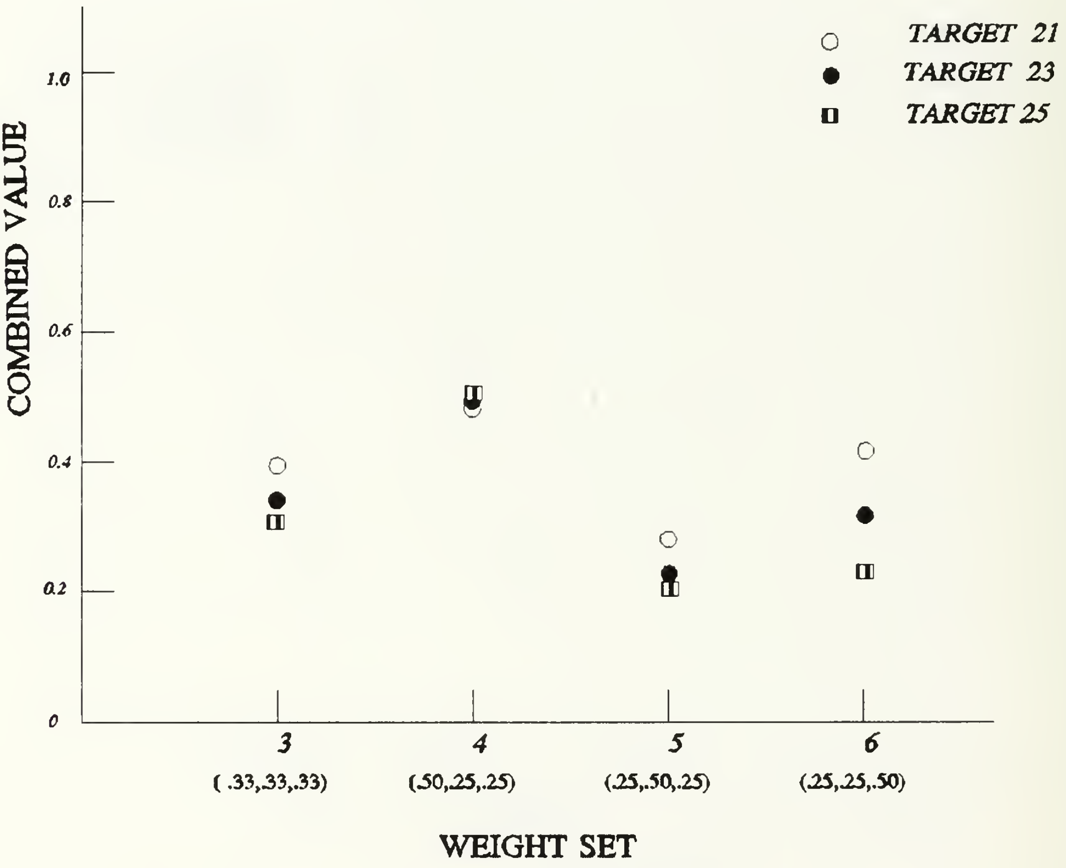

Figure B.13 : 80 Percent Reduction in AD Lethal Radii

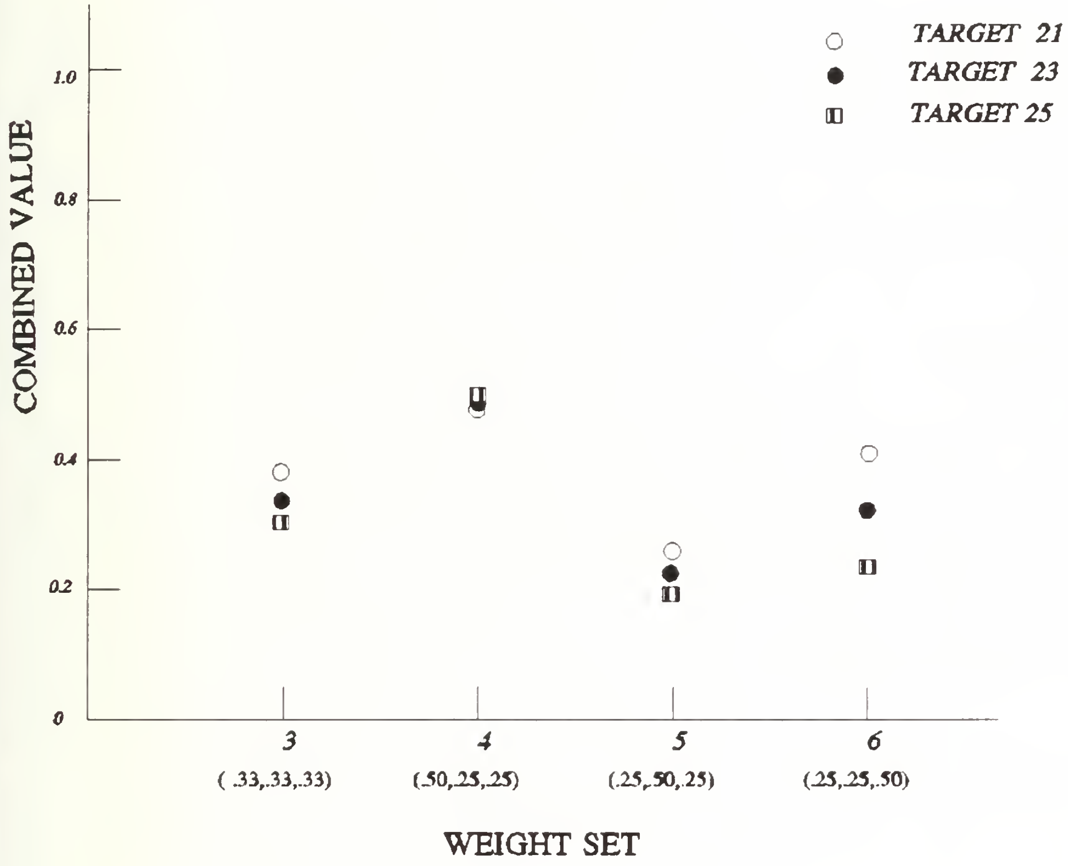

Figure B.14 : 100 Percent Reduction in AD Lethal Radii

APPENDIX C. LIST OF VARIABLES

This appendix presents an alphabetical list which provides definitions of the major variables that are used in the air grid coverage model (Appendix D) and air route selection model (Appendix E). Variables which are used as counters or as dummy arguments in **UNITS** are not included on this list. Variables used to store intermediate results of computations are also omitted from the list. Constant, boolean, scaler, array, record-type, file-type, and linked list variables are listed separately.

A. CONSTANTS

length = square root of number of grids in the grid space

maxvertexsize = desired space for array and linked list data

number_of_grid = number of grids in the grid space

w = width of each air grid

B. BOOLEAN VARIABLES

finish = checking to see whether air grid coverage model computations are completed

inside = to indicate whether the center point of a ground node is inside a specific air grid or not

totally_inside = used to indicate whether the area covered by a ground node is totally inside an air grid or not

C. SCALER VARIABLES

delta = width of a trapezoid (used in model II)

i = counter

number = grid number in which the center point of a ground unit is located

p = estimated probability of kill

r = radius

reduction = percent of reduction from original radius (r)

target = location of target grid

xc = location of the center point on the X-axis

yc = location of the center point on the Y-axis

D. ARRAY VARIABLES

DL = the Difficulty Level (Probability of Kill) of a target in each air grid

pk = probability of kill of a target in each air grid with respect to a ground unit

store = the area of each air grid covered by a ground unit

Tot_area_covered = the total area of each air grid covered by all ground units

E. RECORD-TYPE VARIABLES

air_grid = four corner points of air grids

queue = PriorityQueue

F. FILE-TYPE VARIABLES

infile1 = coordinates of the grid system

infile2 = perceived information of ground units

infile3 = data for Difficulty Level (probability of kill) of each air grid (input from Model I)

outfile1 = result of area-covered and Difficulty Level of each air grid

outfile2 = result of Difficulty Level of each air grid (computed by model I)

outfile3 = route selection model's results

G. LINKED LIST

g = information for each air grid and relative locations of allowable neighbor grids

APPENDIX D

SOURCE CODE OF AIR GRID COVERAGE MODEL (MODEL I)

```
program AIR_GRID_COVERAGE(input,output);
uses PkTool1,PkTool2 ;
var  air_grid : grid_value ;
     inside,totally_inside,finish : boolean ;
     pk,store,DL,Tot_area_covered:keep_value ;
     xc,yc,r,p:real;
     i,number,reduction : integer ;
     infile1,infile2,outfile1,outfile2:text;
     delta : real ;
begin
   assign(infile1,'C:\copy\AXIS55.DAT');
   reset(infile1);
   while not(eof(infile1)) do
     begin
       readln(infile1,i, air_grid[i].ax, air_grid[i].ay,
                         air_grid[i].bx, air_grid[i].by,
                         air_grid[i].cx, air_grid[i].cy,
                         air_grid[i].dx, air_grid[i].dy  );
     end;
   close(infile1);
   delta := 0.01 ;
   assign(outfile1,'C:\copy\DL&COVER.pas');
   assign(outfile2,'C:\copy\DL.OUT');
   rewrite(outfile1);
   rewrite(outfile2);
   reduction := 0 ;
   repeat
       assign(infile2,'c:\copy\GRDNODE.DAT');
       reset(infile2);
       finish := true ;
       Initial_state(DL,Tot_area_covered);
       while not(eof(infile2)) do
         begin
```

```
           Initial_state(Pk,store);
           readln(infile2,xc,yc,r,p);
           r := r - reduction ;
           if ( r > 0) then

             begin
               finish := false ;
               Inside_or_not(inside,number,xc,yc);
               Caculation_of_PK_and_difficulty_level
               (inside,totally_inside,xc,yc,r,p,delta,number,
                air_grid,Pk,store);
               Area_caculation_of_Special_case(inside,
               totally_inside,air_grid,number,xc,yc,
               r,p,delta,Pk,store);
               keep(DL,Tot_area_covered,Pk,store);
             end;
         end ; {while}
       Final_result(DL,Tot_area_covered,outfile1);
       Route_data(DL,outfile2);
       reduction := reduction + 1 ;
       close(infile2);
   until ( finish ) ;
   close(outfile1);
   close(outfile2);
end.
{~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~}
unit PkTool1 ;
interface
 const number_of_grid = 25 ;
{ number of air_grid in the modle }
 type gridetype = record
                  ax :real;
                  ay :real;
                  bx :real;
                  by :real;
                  cx :real;
                  cy :real;
                  dx :real;
                  dy :real;
                 end;
     grid_value = array[1..number_of_grid] of gridetype ;
```

```
    keep_value  = array[1..number_of_grid] of real;
 procedure Find_max_min1_min2_min3(i:integer;xc,yc:real;
          air_grid:gride_value;var max,min1,min2,min3:real) ;
 procedure Caculation_of_PK_and_difficulty_level
               (inside:boolean;var totally_inside:boolean;
                xc,yc,r,p,delta:real;number:integer;
                air_grid:gride_value;
                var Pk,store:keep_value);
implementation
 const w = 10 ;  { width of the air grid equals 10 km }
       length = 5 ;  { dimension = sqrt(number_of_grid) }
 var T : gridetype;
     max,min,min1,min2,min3 : real ;
     x,y : real;
     a,b,d : real;
     i : integer;
     Up,Lo,height,area : real;
 {---------------------------------------------------------------}
 procedure Find_max_min1_min2_min3 ;
   begin
    x := air_grid[i].ax ;
    y := air_grid[i].ay ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    min1:= d ;    { min1 < min2 < min3 }
    max := d ;
    x := air_grid[i].bx ;
    y := air_grid[i].by ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    if ( d > max ) then max := d ;
    if ( d < min1 ) then begin
                           min2 := min1 ;
                           min1 := d ;
                         end
    else min2 := d ;
    x := air_grid[i].cx ;
   y := air_grid[i].cy ;
   a  := ( xc - x ) * ( xc - x ) ;
   b  := ( yc - y ) * ( yc - y ) ;
   if ((a+b)=0.0) then d := 0.0
   else  d := exp( 0.5 * ln(a+b) ) ;
   if ( d > max ) then max := d ;
   if ( d < min2 ) then
   if (d < min1) then begin
                        min3 := min2 ;
                        min2 := min1 ;
                        min1 := d    ;
                      end
   else begin
          min3 := min2 ;
          min2 := d ;
        end ;
   x := air_grid[i].dx ;
   y := air_grid[i].dy ;
   a  := ( xc - x ) * ( xc - x ) ;
   b  := ( yc - y ) * ( yc - y ) ;
   if ((a+b)=0.0) then d := 0.0
   else  d := exp( 0.5 * ln(a+b) ) ;
   if ( d > max ) then max := d ;
   if ( d < min3 ) then
     if ( d < min2 ) then
       begin
         if ( d < min1 ) then
          begin
            min3 := min2 ;
            min2 := min1 ;
            min1 := d    ;
          end
          else begin
            min3 := min2 ;
            min2 := d ;
          end
       end
   else  min3 := d ;
 end; { procedure Find_max_min1_min2_min3 }
{----------------------------------------------------------------}
procedure Caculation_of_PK_and_difficulty_level ;
```

```
begin
 totally_inside := false ;
 max  :=  exp(0.5 * ln(2 * 4 * w * 4 * w)) ;
 min  :=  exp(0.5 * ln(2 * 4 * w * 4 * w)) ;
 min1 :=  exp(0.5 * ln(2 * 4 * w * 4 * w)) ;
 min2 :=  exp(0.5 * ln(2 * 4 * w * 4 * w)) ;
 min3 :=  exp(0.5 * ln(2 * 4 * w * 4 * w)) ;
 if inside then
  begin
  x := air_grid[number].ax ;
  y := air_grid[number].ay ;

  a  := ( xc - x ) * ( xc - x ) ;
  b  := ( yc - y ) * ( yc - y ) ;
  if ((a+b)=0.0) then d := 0.0
  else  d := exp( 0.5 * ln(a+b) ) ;
  min:= d ;
  x := air_grid[number].bx ;
  y := air_grid[number].by ;
  a  := ( xc - x ) * ( xc - x ) ;
  b  := ( yc - y ) * ( yc - y ) ;
  if ((a+b)=0.0) then d := 0.0
  else  d := exp( 0.5 * ln(a+b) ) ;
  if ( d < min ) then  min := d ;
  x := air_grid[number].cx ;
  y := air_grid[number].cy ;
  a  := ( xc - x ) * ( xc - x ) ;
  b  := ( yc - y ) * ( yc - y ) ;
  if ((a+b)=0.0) then d := 0.0
  else  d := exp( 0.5 * ln(a+b) ) ;
  if ( d < min ) then  min := d ;
  x := air_grid[number].dx ;
  y := air_grid[number].dy ;
  a  := ( xc - x ) * ( xc - x ) ;
  b  := ( yc - y ) * ( yc - y ) ;
  if ((a+b)=0.0) then d := 0.0
  else  d := exp( 0.5 * ln(a+b) ) ;
  if ( d < min ) then  min := d ;
  x := air_grid[number].cx ;
  y := yc ;
  a  := ( xc - x ) * ( xc - x ) ;
```

```
    b  := ( yc - y ) * ( yc - y ) ;
    d  := exp( 0.5 * ln(a+b) ) ;  { shortest distance to the left_hand
side }
    if ( d < min ) then  min := d ;
    x := air_grid[number].ax ;
    y := yc ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;{shortest distance to the right
side }
    if ( d < min ) then  min := d ;
    x := xc ;
    y := air_grid[number].cy ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;

    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;    { shortest distance to the top
}
    if ( d < min ) then  min := d ;
    x := xc;
    y := air_grid[number].dy ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
   { shortest distance to the bottom }
    if ( d < min ) then  min := d ;
   end ; { if }
   { ground node is totally inside an air_grid }
   if ( inside and (r <= min) ) then
      begin
        pk[number] := p * (pi * r * r)/(w * w) ;
        store[number] := pi * r * r ;
        totally_inside := true ;
      end
```

```
 {                                8 | 4 | 6
    OTHER CASES ===>            ----|---|----
                                  2 | * | 1
                                ----|---|----
                                  5 | 3 | 7          }
else begin
   for i := 1 to number_of_grid do
    begin
     if not( (inside and (i=number)) ) then
      begin
       T := air_grid[i] ;
       {*********** FOR CASE 1 & 2 *******************}
       if ( (T.by < yc) and (yc < T.ay) ) then
        begin
         {********** CASE 1 ***********************}
         if (T.ax <= xc) then
          begin
           {%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
           { find max ,min,min1,min2 }
           x := air_grid[i].ax ;
           y := air_grid[i].ay ;

           a  := ( xc - x ) * ( xc - x ) ;
           b  := ( yc - y ) * ( yc - y ) ;
           if ((a+b)=0.0) then d := 0.0
           else  d := exp( 0.5 * ln(a+b) ) ;
           min1:= d ;    { min1 < min2 }
           max := d ;
           x := air_grid[i].bx ;
           y := air_grid[i].by ;
           a  := ( xc - x ) * ( xc - x ) ;
           b  := ( yc - y ) * ( yc - y ) ;
           if ((a+b)=0.0) then d := 0.0
           else  d := exp( 0.5 * ln(a+b) ) ;
           if ( d > max ) then max := d ;
           if ( d < min1 ) then begin
                                  min2 := min1 ;
                                  min1 := d ;
                                 end
           else min2 := d ;
           x := air_grid[i].cx ;
           y := air_grid[i].cy ;
```

```
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min2 ) then
   if (d < min1) then begin
                     min2 := min1 ;
                     min1 := d    ;
                   end
   else min2 := d ;
x := air_grid[i].dx ;
y := air_grid[i].dy ;
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min2 ) then
   if ( d < min1 ) then begin
                         min2 := min1 ;
                         min1 := d ;
                       end
   else  min2 := d ;
{ shortest distance from (xc,yc) to the
      left_hand side of the tatgert air gride }
x := air_grid[i].ax ;
y := yc ;
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then min := 0.0
else min  := exp( 0.5 * ln(a+b) ) ;
{%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
if ( r <= min ) then pk[i] := 0
else if ( r >= max ) then
       begin
         pk[i] := p ;
         store[i] :=w * w ;
       end
else begin
      if ((min1 < r) and (min2 < r)) then
```

```
                begin
                 Lo := T.by ;
                 Up := T.ay ;
                end
              else if ((r>min)and((r<min1) and
             (r<min2))) then
                     begin
                      y:=exp(0.5*ln(r*r-(T.ax-xc)*
                         (T.ax-xc)))+yc;
                      Up := y ;
                      Lo := 2 * yc - y ;
                     end
              else if (yc > (T.ay+T.by)/2) then
                begin
                  Up := T.ay ;
                  y:=exp(0.5*ln(r*r-(T.ax-xc)*
                     (T.ax-xc)))+yc;
                  Lo := abs(y-2*(y-T.ay)-2*
                        abs(T.ay-yc)) ;
                end
              else begin
                     Lo := T.by ;
                     y:=exp(0.5*ln(r*r-(T.ax-xc)*
                        (T.ax-xc))) + yc;
                     Up := y ;
                   end ;
             { Area caculation portion }
              y := Lo + delta / 2 ;
              area := 0 ;
              while ( y <= Up ) do
                begin
                  x:=exp(0.5*ln(r*r-(y-yc)*
                     (y-yc)))+xc;
                  height:= x-xc-abs(T.ax-xc) ;
                  area := area + height * delta ;
                  y := y + delta ;
                end; {while}
              pk[i] := p * area / ( w * w ) ;
              store[i] := area ;
             end
     end  {if}
```

```
{************ END OF CASE 1 ****************}
{*************** CASE  2********************}
else
  begin
    {%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
    { find max ,min,min1,min2 }
    x := air_grid[i].ax ;
    y := air_grid[i].ay ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    min1:= d ;     { min1 < min2 }
    max := d ;
    x := air_grid[i].bx ;
    y := air_grid[i].by ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    if ( d > max ) then max := d ;
    if ( d < min1 ) then begin
                          min2 := min1 ;
                          min1 := d ;
                         end
    else min2 := d ;
    x := air_grid[i].cx ;
    y := air_grid[i].cy ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    if ( d > max ) then max := d ;
    if ( d < min2 ) then
       if (d < min1) then begin
                            min2 := min1 ;
                            min1 := d    ;
                          end
       else min2 := d ;
    x := air_grid[i].dx ;
    y := air_grid[i].dy ;
```

```
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min2 ) then
   if ( d < min1 ) then begin
                          min2 := min1 ;
                                min1 := d ;
                                    end
   else  min2 := d ;
{shortest distance from (xc,yc) to the
      right_hand side of the target air_grid}
x := air_grid[i].cx ;
y := yc ;
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then min := 0.0
else min  := exp( 0.5 * ln(a+b) ) ;
{%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
if ( r <= min ) then pk[i] := 0
else if ( r >= max ) then
       begin
         pk[i] := p ;
         store[i] := w * w ;
       end
else begin
      if ((min1 < r) and (min2 < r)) then
        begin
         Lo := T.dy ;
         Up := T.cy ;
        end
      else if ((r>min)and((r<min1)
              and(r<min2))) then
        begin
          y:=exp(0.5*ln(r*r-(T.cx-xc)*
             (T.cx-xc)))+yc;
          Up := y ;
          Lo := 2 * yc - y ;
        end
      else if (yc > (T.cy+T.dy)/2) then
```

```
                begin
                  Up := T.cy ;
                  y:=exp(0.5*ln(r*r-(T.cx-xc)*
                     (T.cx-xc)))+yc;
                  Lo := 2 * yc - y ;
                end
              else begin
                    Lo := T.dy ;
                    y:=exp(0.5*ln(r*r-(T.cx-xc)*
                       (T.cx-xc)))+yc;
                    Up := y ;
                   end ;
              { Area caculation portion }
              y := Lo + delta / 2 ;
              area := 0 ;
              while ( y <= Up ) do
               begin
                x := exp(0.5*ln(r*r-(y-yc)*
                     (y-yc))) + xc ;
                height:= x-T.cx ;
                area := area + height * delta ;
                y := y + delta ;
               end; {while}
              pk[i] := p * area / ( w * w ) ;
              store[i] := area ;
             end
      end
    {********** END OF CASE 2 ******************}
  end  {if}
{************* END OF CASE 1 & 2 ***************}
{############# FOR CASE 3 & 4  #################}
else if ( (T.cx <= xc) and (xc <= T.ax) ) then
  begin
    {**************** CASE 3 *******************}
    if (yc <= T.dy) then
      begin
        {%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
        { find max ,min,min1,min2 }
        x := air_grid[i].ax ;
        y := air_grid[i].ay ;
```

```
a   := ( xc - x ) * ( xc - x ) ;
b   := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
min1:= d ;     { min1 < min2 }
max := d ;
x := air_grid[i].bx ;
y := air_grid[i].by ;
a   := ( xc - x ) * ( xc - x ) ;
b   := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min1 ) then begin
                      min2 := min1 ;
                      min1 := d ;
                     end
else min2 := d ;
x := air_grid[i].cx ;
y := air_grid[i].cy ;
a   := ( xc - x ) * ( xc - x ) ;
b   := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min2 ) then
   if (d < min1) then begin
                        min2 := min1 ;
                        min1 := d    ;
                      end
   else min2 := d ;
x := air_grid[i].dx ;
y := air_grid[i].dy ;
a   := ( xc - x ) * ( xc - x ) ;
b   := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then d := 0.0
else  d := exp( 0.5 * ln(a+b) ) ;
if ( d > max ) then max := d ;
if ( d < min2 ) then
   if ( d < min1 ) then begin
```

```
                           min2 := min1 ;
                           min1 := d ;
                         end
   else  min2 := d ;
{ shortest distance from (xc,yc) to the
bottom of the target air_grid}
x := xc ;
y := air_grid[i].dy ;
a  := ( xc - x ) * ( xc - x ) ;
b  := ( yc - y ) * ( yc - y ) ;
if ((a+b)=0.0) then min := 0.0
else min  := exp( 0.5 * ln(a+b) ) ;
{%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
if ( r <= min ) then pk[i] := 0
else if ( r >= max ) then
       begin
         pk[i] := p ;
         store[i] := w * w ;
       end
else begin
      if ((min1 < r) and (min2 < r)) then
        begin
         Lo := T.dx ;
         Up := T.bx ;
        end
      else if ((r>min)and((r<min1)
               and(r<min2))) then
        begin
          x:=exp(0.5*ln(r*r-(T.by-yc)*
             (T.by-yc)))+xc;
          Up := x ;
          Lo := 2 * xc - x ;
        end
      else if (xc > (T.dx+T.bx)/2) then
        begin
          Up := T.bx ;
          x:=exp(0.5*ln(r*r-(T.by-yc)*
             (T.by-yc)))+xc;
          Lo := 2 * xc - x ;
        end
      else begin
```

```
                Lo := T.dx ;
                x:=exp(0.5*ln(r*r-(T.by-yc)*
                   (T.by-yc)))+xc;
                Up := x ;
               end ;
          { Area caculation portion }
          x := Lo + delta / 2 ;
          area := 0 ;
          while ( x <= Up ) do
           begin
            y := exp(0.5*ln(r*r-(x-xc)*
                 (x-xc))) + yc ;
            height:= y-yc-abs(T.by-yc) ;
            area := area + height * delta ;
            x := x + delta ;
           end; {while}
          pk[i] := p * area / ( w * w ) ;
          store[i] := area ;
         end
  end  {if}
{************* END OF CASE 3 ***************}
{*************** CASE 4 ********************}
else
  begin
    {%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
    { find max ,min,min1,min2 }
    x := air_grid[i].ax ;
    y := air_grid[i].ay ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d := exp( 0.5 * ln(a+b) ) ;
    min1:= d ;    { min1 < min2 }
    max := d ;
    x := air_grid[i].bx ;
    y := air_grid[i].by ;
    a  := ( xc - x ) * ( xc - x ) ;
    b  := ( yc - y ) * ( yc - y ) ;
    if ((a+b)=0.0) then d := 0.0
    else  d  := exp( 0.5 * ln(a+b) ) ;
    if ( d > max ) then max := d ;
```

```
       if ( d < min1 ) then begin
                              min2 := min1 ;
                              min1 := d ;
                             end
       else min2 := d ;
       x := air_grid[i].cx ;
       y := air_grid[i].cy ;
       a  := ( xc - x ) * ( xc - x ) ;
       b  := ( yc - y ) * ( yc - y ) ;
       if ((a+b)=0.0) then d := 0.0
       else  d := exp( 0.5 * ln(a+b) ) ;
       if ( d > max ) then max := d ;
       if ( d < min2 ) then
          if (d < min1) then begin
                                min2 := min1 ;
                                min1 := d ;
                              end
          else min2 := d ;
       x := air_grid[i].dx ;
       y := air_grid[i].dy ;
       a  := ( xc - x ) * ( xc - x ) ;
       b  := ( yc - y ) * ( yc - y ) ;
       if ((a+b)=0.0) then d := 0.0
       else  d := exp( 0.5 * ln(a+b) ) ;

       if ( d > max ) then max := d ;
       if ( d < min2 ) then
          if ( d < min1 ) then begin
                                  min2 := min1 ;
                                  min1 := d ;
                                end
          else  min2 := d ;
       { shortest distance from (xc,yc) to the
top of the target air_grid}
       x := xc ;
       y := air_grid[i].cy ;
       a  := ( xc - x ) * ( xc - x ) ;
       b  := ( yc - y ) * ( yc - y ) ;
       if ((a+b)=0.0) then min := 0.0
       else min  := exp( 0.5 * ln(a+b) ) ;
       {%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%}
```

```
if ( r <= min ) then pk[i] := 0
else if ( r >= max ) then
       begin
         pk[i] := p ;
         store[i] := w * w ;
       end
else begin
      if ((min1 < r) and (min2 < r)) then
        begin
         Lo := T.dx ;
         Up := T.bx ;
        end
      else if ((r>min)and((r<min1)
               and(r<min2))) then
        begin
          x:=exp(0.5*ln(r*r-(T.ay-yc)*
             (T.ay-yc)))+xc;
          Up := x ;
          Lo := 2 * xc - x ;
        end
      else if (xc > (T.dx+T.bx)/2) then
        begin
          Up := T.ax ;
          x:=exp(0.5*ln(r*r-(T.ay-yc)*
             (T.ay-yc)))+xc;
          Lo := 2 * xc - x ;
        end
      else begin
            Lo := T.cx ;
            x:=exp(0.5*ln(r*r-(T.cy-yc)*
               (T.cy-yc)))+xc;
            Up := x ;
           end ;
      { Area caculation portion }
      x := Lo + delta / 2 ;
      area := 0 ;
      while ( x <= Up ) do
       begin
        y := exp(0.5*ln(r*r-(x-xc)*
             (x-xc))) + yc ;
        height:= abs(y-yc-abs(T.cy-yc)) ;
```

```
                area := area + height * delta ;
                x := x + delta ;
               end; {while}
              pk[i] := p * area / ( w * w ) ;
              store[i] := area ;
             end
      end
    {************* END OF CASE 4 ***************}
  end
{############# END 0F CASE 3 & 4 ###############}
{%%%%%%%%%%%%%%%%% FOR CASE 5 %%%%%%%%%%%%%%%%%%}
else if ( (T.dx > xc) and (T.dy >= yc) ) then
  begin
    Find_max_min1_min2_min3(i,xc,yc,air_grid,
                            max,min1,min2,min3) ;
    if ( r <= min1 ) then pk[i] := 0
    else if ( r >= max ) then
           begin
             pk[i] := p ;
             store[i] := w * w ;
           end
        else begin
              if ((r >min1) and (r <max)) then
                begin
                 Lo := T.dx ;
                 x:=exp(0.5*ln(r*r-(T.dy-yc)*
                    (T.dy-yc)))+xc;
                 if ( x > T.ax ) then Up := T.ax
                 else Up := x ;
                end ;
              { Area caculation portion }
              x := Lo + delta / 2 ;
              area := 0 ;
              while ( x <= Up ) do
               begin
                y := exp(0.5*ln(r*r-(x-xc)*
                     (x-xc))) + yc ;
                if (y > T.ay) then y := T.ay ;
                height:= y - T.dy ;
                area := area + height * delta ;
                x := x + delta ;
              end; {while}
             if ( area > w*w ) then area := w*w;
             pk[i] := p * area / ( w * w ) ;
             store[i] := area ;
            end
  end
{%%%%%%%%%%%%% END OF CASE 5 %%%%%%%%%%%%%%%%%%%}
{%%%%%%%%%%%%%%%% FOR CASE 6 %%%%%%%%%%%%%%%%%%%}
else if ( (T.ax < xc) and (T.ay <= yc) ) then
  begin
    Find_max_min1_min2_min3(i,xc,yc,air_grid,
    max,min1,min2,min3) ;
    if ( r <= min1 ) then pk[i] := 0
    else if ( r >= max ) then begin
                                pk[i] := p ;
                                store[i] := w*w;
                              end
    else begin
           if ((r >min1) and (r <max)) then
                begin
                  Up := T.ax;
                  x:=exp(0.5*ln(r*r-(T.ay-yc)*
                     (T.ay-yc)))+xc;
                 Lo := 2 * xc - x ;
                 if (Lo < T.cx) then Lo := T.cx ;
                end ;
           { Area caculation portion }
           x := Lo + delta / 2 ;
           area := 0 ;
           while ( x <= Up ) do
             begin
               y := exp(0.5*ln(r*r-(x-xc)*
                    (x-xc))) + yc ;
               height := T.ay - (2*yc-y);
               if (height > w) then height := w ;
               area := area + height * delta ;
               x := x + delta ;
             end; {while}
           pk[i] := p * area / ( w * w ) ;
           store[i] := area ;
         end
  end
{%%%%%%%%%%%% END OF CASE 6 %%%%%%%%%%%%%%%%%%}
{@@@@@@@@@@@@@@@@ FOR CASE 7 @@@@@@@@@@@@@@@@@@@@}
else if ( (T.bx < xc) and (T.by >= yc) ) then
  begin
    Find_max_min1_min2_min3(i,xc,yc,air_grid,
    max,min1,min2,min3) ;
    if ( r <= min1 ) then pk[i] := 0
    else if ( r >= max ) then begin
                                 pk[i] := p ;
                                 store[i] := w*w ;
                               end
    else begin
           if ((r >min1) and (r <max)) then
             begin
               Up := T.bx ;
               x:=exp(0.5*ln(r*r-(T.dy-yc)*
                  (T.dy-yc)))+xc;
               Lo := 2 * xc - x ;
               if ( Lo < T.dx ) then Lo := T.dx
             end ;
           { Area caculation portion }
           x := Lo + delta / 2 ;
           area := 0 ;
           while ( x <= Up ) do
             begin
               y := exp(0.5*ln(r*r-(x-xc)*
                    (x-xc))) + yc ;
               if (y > T.ay) then y := T.ay ;
               height:= y - T.by ;
               area := area + height * delta ;
               x := x + delta ;
             end; {while}
           pk[i] := p * area / ( w * w ) ;
           store[i] := area ;
         end
  end
{@@@@@@@@@@@@@ END OF CASE 7 @@@@@@@@@@@@@@@@@@@@}
{@@@@@@@@@@@@@@@@ FOR CASE 8 @@@@@@@@@@@@@@@@@@@@}
else if ( (T.cx > xc) and (T.cy <= yc) ) then
  begin
```

```
                Find_max_min1_min2_min3(i,xc,yc,air_grid,
                max,min1,min2,min3) ;
                if ( r <= min1 ) then pk[i] := 0
                else if ( r >= max ) then begin
                                            pk[i] := p ;
                                            store[i] := w*w ;
                                          end
                else begin
                       if ((r >min1) and (r <max)) then
                           begin
                            Lo := T.cx ;
                            x:=exp(0.5*ln(r*r-(T.ay-yc)*
                               (T.ay-yc)))+xc;
                            Up := x ;
                            if (Up > T.ax) then Up := T.ax ;
                           end ;
                       { Area caculation portion }
                       x := Lo + delta / 2 ;
                       area := 0 ;
                       while ( x <= Up ) do
                         begin
                           y := exp(0.5*ln(r*r-(x-xc)*
                                (x-xc))) + yc ;
                           height := T.ay - (2*yc-y);
                           if (height > w) then height := w ;
                           area := area + height * delta ;
                           x := x + delta ;
                         end; {while}
                       pk[i] := p * area / ( w * w ) ;
                       store[i] := area ;
                     end
              end
            {@@@@@@@@@@@@@ END OF CASE 8 @@@@@@@@@@@@@@@@@@@@}
          end; { if not( (inside and (i=number)) ) }
        end; { for }
      end ;  { else }
   end;
 {-------------------------------------------------------------}
end. {unit}
{~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~}
```

```
unit PkTool2 ;
interface
 uses PkTool1 ;
 procedure Inside_or_not(var inside:boolean;var number:
 integer;A,B:real);
 procedure Initial_state(var keep1,keep2:keep_value);
 function Boundary_check(xc,yc,r:real;air_grid:gride_value):
 boolean;
 procedure Area_caculation_of_Special_case
           ( inside,totally_inside:boolean;air_grid:gride_value;
             number:integer; xc,yc,r,p,delta:real;var
             Pk,store:keep_value);
 procedure Keep(var DL,Tot_area_covered:keep_value;Pk,store:
                keep_value);
 procedure Final_result(DL,Tot_area_covered:keep_value;var
               outfile1:text);
 procedure Route_data(DL:keep_value;var outfile2:text);
implementation
 const w = 10 ; { unit length of the air grid equals 10 km }
       length = 5 ;  { length = sqrt(M) }
 var T : gridetype;
     x,y,xc,yc : real;
     a,b,d : real;
     height,area,sum,Up,Lo : real;
     i : integer ;
 {--------------------------------------------------------------}
 procedure Inside_or_not ;
   begin
    xc := A ;
    yc := B ;
    xc := xc / w ;
    yc := yc / w ;
    number := number_of_grid + 1 ;
    if ( ( xc = 0.0 ) or ( yc = 0.0 ) ) then  inside := false
    else if ((xc < 1) and (yc < 1)) then
      begin
        inside := true ;
        number := 1 ;
      end
    else if ((xc < 1) and (yc > 1)) then
      begin
    if ( (yc/trunc(yc)) = 1 ) then  inside := false
    else begin
          inside := true ;
          number := length * trunc(yc) + 1 ;
         end
  end
else if ((xc > 1) and (yc < 1)) then
  begin
    if ( (xc/trunc(xc)) = 1 ) then  inside := false
    else begin
          inside := true ;
          number := trunc(xc) + 1 ;
         end
  end
else if ((xc < 1) and (abs(yc/trunc(yc))=1)) then
       inside := false
else if ((yc < 1) and (abs(xc/trunc(xc))=1)) then
       inside := false
else if ((abs(xc/trunc(xc))=1) or (abs(yc/trunc(yc))=1)) then
       inside := false
else begin
       inside := true ;
       if ((0 < xc) and (xc < 1)) then
         begin
           if ((0 < yc) and (yc < 1)) then number := 1 ;
           if ((1 < yc) and (yc < 2)) then number := 6 ;
           if ((2 < yc) and (yc < 3)) then number := 11 ;
           if ((3 < yc) and (yc < 4)) then number := 16 ;
           if ((4 < yc) and (yc < 5)) then number := 21 ;
         end
       else if ((1 < xc) and (xc < 2)) then
         begin
           if ((0 < yc) and (yc < 1)) then number := 2 ;
           if ((1 < yc) and (yc < 2)) then number := 7 ;
           if ((2 < yc) and (yc < 3)) then number := 12 ;
           if ((3 < yc) and (yc < 4)) then number := 17 ;
           if ((4 < yc) and (yc < 5)) then number := 22 ;
         end
       else if ((2 < xc) and (xc < 3)) then
         begin
           if ((0 < yc) and (yc < 1)) then number := 3 ;
       if ((1 < yc) and (yc < 2)) then number := 8 ;
       if ((2 < yc) and (yc < 3)) then number := 13 ;
       if ((3 < yc) and (yc < 4)) then number := 18 ;
       if ((4 < yc) and (yc < 5)) then number := 23 ;
      end
     else if ((3 < xc) and (xc < 4)) then
      begin
       if ((0 < yc) and (yc < 1)) then number := 4 ;
       if ((1 < yc) and (yc < 2)) then number := 9 ;
       if ((2 < yc) and (yc < 3)) then number := 14 ;
       if ((3 < yc) and (yc < 4)) then number := 19 ;
       if ((4 < yc) and (yc < 5)) then number := 24 ;
      end
     else if ((4 < xc) and (xc < 5)) then
      begin
       if ((0 < yc) and (yc < 1)) then number := 5 ;
       if ((1 < yc) and (yc < 2)) then number := 10 ;
       if ((2 < yc) and (yc < 3)) then number := 15 ;
       if ((3 < yc) and (yc < 4)) then number := 20 ;
       if ((4 < yc) and (yc < 5)) then number := 25 ;
      end
     else writeln(' Error from input data  !!! ') ;
    end ;
  xc := xc * w ;
  yc := yc * w ;
 end;
{---------------------------------------------------------------}
procedure Initial_state ;
 begin
  for i := 1 to number_of_grid do
   begin
    keep1[i] := 0.0 ;
    keep2[i] := 0.0 ;
   end;
 end;
{---------------------------------------------------------------}
function Boundary_check ;
  begin
  if ((r>(air_grid[length].ax-xc))or(r>(air_grid
    [number_of_grid].ay-yc))or((r>(yc-air_grid[1].by))
    or(r>(xc-air_grid[1].dx)) ) ) then Boundary_check := true
    else Boundary_check := false ;
   end ;
{--------------------------------------------------------------}
procedure Area_caculation_of_Special_case ;
  var i : integer ;
      area : real ;
  begin
       if not(totally_inside) then
        if (inside and not(Boundary_check(xc,yc,r,
            air_grid))) then
          begin
            T := air_grid[number] ;
            area := pi * r * r ;
            i := 1 ;
            while  ( i <= number_of_grid )  do
              begin
                if (i <> number) then  area := area - store[i] ;
                i := i + 1 ;
              end ; {while}
            pk[number] := p * area / (w * w) ;
            store[number] := area;
          end
        else if (inside and Boundary_check(xc,yc,r,air_grid))
            then begin
                    sum := 0.0 ;
                    T := air_grid[number] ;
                    {### for the upper_right part ###}
                    Lo := xc ;
                    Up := xc + r ;
                    if (Up > T.ax) then Up := T.ax ;
                    { Area caculation portion }
                    x := Lo + delta / 2 ;
                    area := 0 ;
                    while ( x <= Up ) do
                      begin
                        y := exp(0.5*ln(r*r-(x-xc)*(x-xc)))+yc ;
                        if (y > T.ay) then y := T.ay ;
                        height:= y - yc ;
                        area := area + height * delta ;
                        x := x + delta ;
                      end; {while}
```

```
sum := sum + area ;
{##################################}
{### for the upper_left part ###}
Up := xc ;
Lo := xc - r ;
if (Lo < T.cx) then Lo := T.cx ;
{ Area caculation portion }
x := Lo + delta / 2 ;
area := 0 ;
while ( x <= Up ) do
  begin
    y := exp(0.5*ln(r*r-(x-xc)*(x-xc)))+yc ;
    if (y > T.ay) then y := T.ay ;
    height:= y - yc ;
    area := area + height * delta ;
    x := x + delta ;
  end; {while}
sum := sum + area ;
{##################################}
{### for the down_right part ###}
Lo := xc ;
Up := xc + r ;
if (Up > T.ax) then Up := T.ax ;
{ Area caculation portion }
x := Lo + delta / 2 ;
area := 0 ;
while ( x <= Up ) do
  begin
    y := exp(0.5*ln(r*r-(x-xc)*(x-xc)))+yc ;
    y := 2 * yc - y ;
    if (y < T.by) then y := T.by ;
    height:= yc - y ;
    area := area + height * delta ;
    x := x + delta ;
  end; {while}
sum := sum + area ;
{##################################}
{### for the down_left part ###}
Up := xc ;
Lo := xc - r ;
if (Lo < T.cx) then Lo := T.cx ;
```

```
                    { Area caculation portion }
                    x := Lo + delta / 2 ;
                    area := 0 ;
                    while ( x <= Up ) do
                      begin
                        y := exp(0.5*ln(r*r-(x-xc)*(x-xc)))+yc ;
                        y := 2 * yc - y ;
                        if (y < T.by) then y := T.by ;
                        height:= yc - y ;
                        area := area + height * delta ;
                        x := x + delta ;
                      end; {while}
                    sum := sum + area ;
                    {#################################}
                    pk[number] := p * sum / (w * w) ;
                    store[number] := sum;
                 end;
  end;
{---------------------------------------------------------------}
procedure Keep ;
  begin
    for i := 1 to number_of_grid do
      begin
        DL[i] := DL[i] + Pk[i] ;
        Tot_area_covered[i] := Tot_area_covered[i] + store[i] ;
      end;
  end;
{---------------------------------------------------------------}
procedure Final_result ;
  begin
    for i := 1 to number_of_grid do
       writeln(outfile1,'DL[',i:2,']  =  ',DL[i]:7:6,'       ',
              'Total_area_covered[',i:2,']  =
',Tot_area_covered[i]:7:6);
  end;
{---------------------------------------------------------------}
procedure Route_data ;
  begin
    for i := 1 to number_of_grid do
       writeln(outfile2,i:2,'   ',DL[i]:3:2);
       writeln(outfile2);
```

```
   end;
 {-----------------------------------------------------------}
end. {unit}
```

APPENDIX E

SOURCE CODE OF AIR ROUTE SELECTION MODEL (MODEL II)

```
program Route_Select(input,output);
uses MRoutool,PriQTool,PKTool1;
var target : integer ;
    g : VertexList ;
    queue : PrioriQueueType ;
    DL : Keep_value ;
    infile3,outfile3 : text ;
begin
  target := 13 ;
  assign(infile3,'C:\COPY\DL2.PAS');
  assign(outfile3,'C:\COPY\RESULT.PAS');
  reset(infile3);
  rewrite(outfile3);
  Transfer(infile,DL);
  NetworkInput(g,DL);
  Search_part(g,target,DL);
  Result_Print(outfile3,g,target,DL) ;
  close(infile3);
  close(outfile3);
end.
{~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~}

unit MRoutool;
interface
  uses  PriQTool ;
  const MAXVERTEXSIZE = 25 ;
        LENGTH = 5 ;

  type  VertexPTR=^AdjVertexType;
        AdjVertexType=record
                        VertexNumber:integer;
                        Dis         :real;
                        Next        :VertexPTR;
                      end;
     { Dis means distance from host gride to the adjacent gride }
```

```
        VertexType=record
                     visited       :boolean;
                     Hardness      :real;
                     next_choice   :integer;
                     AdjVertexList:VertexPTR;
                   end;
      { Hardness means sum of the effects of those difficulty level &
       distance from current gride to the target gride }
        VertexList = array[1..MAXVERTEXSIZE] of VertexType;
  procedure Transfer(var infile:text;var DL:Keep_value);
  procedure NetworkInput(var g:VertexList;DL:Keep_value);
  procedure Search_part(var VertexList;target:integer;
            DL:Keep_value);
  procedure Result_Print(var outfile:text;g:VertexList;
            target:integer;DL:Pk_DL) ;
implementation
{----------------------------------------------------------------}
 procedure Transfer(var infile:text;var DL:Keep_value);
  var i : integer;
      DL :real ;
      answer:char;
   begin
     for i := 1 to MAXVERTEXSIZE do
       begin
        readln(infile,i,DL[i]);
        writeln(outfile,i:2,'    ',DL[i]:5:2);
       end;
   end;
{----------------------------------------------------------------}
 procedure NetworkInput ;
  var i,AdjElement:integer;
      CE:VertexPTR;
      check:boolean;
  begin
    for i := 1 to MAXVERTEXSIZE  do
      begin
        g[i].visited      := false ;
        g[i].Hardness     := 999 ;
        g[i].next_choice  := MAXVERTEXSIZE + 1 ;
        g[i].AdjVertexList:= NIL ;
      end ;
```

```
for i := 1 to MAXVERTEXSIZE  do
 begin
  check := false ;
  New(g[i].AdjVertexList);
  CE := g[i].AdjVertexList;
  {-------------------- 1 -------------------------}
  if ( i < (MAXVERTEXSIZE - (LENGTH -1)) ) then
   begin
    AdjElement := i + LENGTH ;
    if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
   then
     begin
      check := true ;
      CE^.VertexNumber:= AdjElement ;
      CE^.Dis := 1 ;
      CE^.Next:=NIL;
     end;
   end;
  {-------------------- 2 ------------------------}
  if ( ( i < (MAXVERTEXSIZE - (LENGTH -1)) ) and
       ((i mod LENGTH) <> 0 ) ) then
   begin
    AdjElement := i + ( LENGTH + 1 ) ;
    if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
   then
      begin
        if check then

          begin
            New(CE^.Next) ;
            CE :=CE^.Next ;
          end ;
        CE^.VertexNumber:= AdjElement ;
        CE^.Dis := sqrt(2) ;
        CE^.Next:=NIL;
        check := true ;
      end;
   end;
  {-------------------- 3 ------------------------}
  if ( (i mod LENGTH) <> 0 ) then
   begin
  AdjElement := i + 1 ;
  if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
 then
    begin
      if check then
        begin
          New(CE^.Next) ;
          CE :=CE^.Next ;
        end ;
      CE^.VertexNumber:= AdjElement ;
      CE^.Dis := 1 ;
      CE^.Next:=NIL;
      check := true ;
    end;
 end;
{---------------------- 4 --------------------------}
if ( (i > LENGTH) and ((i mod LENGTH) > 0 ) ) then
 begin
  AdjElement := i - ( LENGTH - 1 ) ;
  if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
 then
    begin
      if check then
        begin
          New(CE^.Next) ;
          CE :=CE^.Next ;
        end ;
      CE^.VertexNumber:= AdjElement ;

      CE^.Dis := sqrt(2) ;
      CE^.Next:=NIL;
      check := true ;
    end;
 end;
{---------------------- 5 ---------------------------}
if ( i > LENGTH ) then
 begin
  AdjElement := i - LENGTH ;
   if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
  then
    begin
```

```
      if check then
        begin
          New(CE^.Next) ;
          CE :=CE^.Next ;
        end ;
      CE^.VertexNumber:= AdjElement ;
      CE^.Dis := 1 ;
      CE^.Next:=NIL;
      check := true ;
    end;
 end;
{-------------------- 6 ------------------------}
if ( (i> LENGTH) and (((i-1) mod LENGTH) <> 0 ) ) then
 begin
  AdjElement := i - ( LENGTH + 1 ) ;
  if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
 then
    begin
      if check then
        begin
          New(CE^.Next) ;
          CE :=CE^.Next ;
        end ;
      CE^.VertexNumber:= AdjElement ;
      CE^.Dis := sqrt(2) ;
      CE^.Next:=NIL;
      check := true ;
    end;
 end;
{-------------------- 7 ------------------------}
if  (((i-1) mod LENGTH) <> 0 ) then
 begin
  AdjElement := i - 1 ;
  if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
 then
    begin
      if check then
        begin
          New(CE^.Next) ;
          CE :=CE^.Next ;
        end ;
```

```
          CE^.VertexNumber:= AdjElement ;
          CE^.Dis := 1 ;
          CE^.Next:=NIL;
          check := true ;
        end;
     end;
    {-------------------- 8 ------------------------}
    if ((((i-1) mod LENGTH) <> 0 ) and
        ( i < (MAXVERTEXSIZE-(LENGTH-1))) )  then
     begin
      AdjElement := i + ( LENGTH - 1 ) ;
      if ((AdjElement >= 1) and (AdjElement <= MAXVERTEXSIZE))
     then
        begin
          if check then
            begin
              New(CE^.Next) ;
              CE :=CE^.Next ;
            end ;
          CE^.VertexNumber:= AdjElement ;
          CE^.Dis := sqrt(2) ;
          CE^.Next:=NIL;
          check := true ;
        end;
     end;
    {-------------------------------------------------}
    end; {for}
 end;   {end of NetworkInput}
{----------------------------------------------------------------}
procedure Search_part ;
 var T,Temp : VertexPTR ;
     host,i,j,counter,choice : integer ;
     min,Hardness : real ;
     X : DataType ;
     V : array[1..MAXVERTEXSIZE] of integer;
     pQueue : PriorityQueueType ;
     check,change : boolean ;
 begin
   InitializePriorityQueue(pQueue);
   g[target].visited := true ;
   g[target].Hardness := 0.0 ;
```

```
g[target].next_choice := 0 ;
X.gride    := target ;
if ( (w2 * DL[target]) = 0 ) then X.Hardness := 0
else X.Hardness := 1 / (w2 * DL[target]) ;
InsertPriorityQueue(pQueue,X) ;
while not(EmptyPriorityQueue(pQueue)) do
  begin
    host := ExtractMaximum(pQueue) ;
    T := g[host].AdjVertexList ;
    while ( T <> NIL ) do
      begin
           if ( host = target ) then
            begin
              Hardness := w2 * DL[host] + w1 * W * T^.Dis ;
              g[T^.VertexNumber].visited    := true ;
              g[T^.VertexNumber].Hardness   := Hardness ;
              g[T^.VertexNumber].next_choice:= host ;
              X.gride   := T^.VertexNumber ;
              if ((g[T^.VertexNumber].Hardness + w2 *
        DL[X.gride]) = 0)
              then X.Hardness:= 0
              else X.Hardness:=1/(g[T^.VertexNumber].Hardness
                             + w1 * DL[X.gride]);
              InsertPriorityQueue(pQueue,X) ;
              T := T^.Next ;
            end
           else begin
                  min := 888 ;
                  choice := MAXVERTEXSIZE + 1 ;

                  if not(g[T^.VertexNumber].visited) then
                    begin
                      Temp :=  g[T^.VertexNumber].
                              AdjVertexList ;
                      while ( Temp <> NIL ) do
                        begin
                          if ((g[Temp^.VertexNumber].visited)
                         then
                              begin
                               Hardness := g[Temp^.VertexNumber].
                               Hardness + w2 * DL[Temp^.VertexNumber]
                                        .
```

```
                                 + w1 * W * Temp^.Dis ;
                                 if ( Hardness < min ) then
                                   begin
                                      min := Hardness;
                                      choice := Temp^.VertexNumber ;
                                    end;
                                end;
                              Temp := Temp^.Next ;
                            end ; { while }
                          g[T^.VertexNumber].visited    := true ;
                          g[T^.VertexNumber].Hardness   := min ;
                          g[T^.VertexNumber].next_choice:=choice;
                          X.gride   := T^.VertexNumber ;
                          if ( (min + w2 * DL[X.gride]) = 0 )
                      then X.Hardness := 0
                          else X.Hardness:= 1 / (min + w2 *
                                          DL[X.gride]);
                          InsertPriorityQueue(pQueue,X) ;
                          T := T^.Next ;
                        end
                      else T := T^.Next ;
                    end ;
             end; { end of while ( T <> NIL ) }
      end ; { end of outside while loop  }
{--------------------------------------------------------------}
 procedure Result_Print ;
  var i,n,count : integer ;
  begin
    writeln(outfile,'Gride i':4,'DL[i]':7,'path to target':24,
                               'Hardness':15,'% Hardness reduced':22);
    for i := 1 to MAXVERTEXSIZE do
      begin
        n := i ;
        write(outfile,i:4,DL[i]:9:1);
        if (n = target) then
          begin
              write(outfile,'0':13);
              write(outfile,'0.0':25);
              writeln(outfile,'???':18);
              writeln(outfile);
          end
      else begin
            write(outfile,i:8);
            count := 0 ;
            repeat
              count := count + 1 ;
              write(outfile,' - ',g[n].next_choice:2);
              n := g[n].next_choice ;
            until ( n = target) ;
            while (count < 3) do
              begin
                write(outfile,'  ':5);
                count := count + 1 ;
              end;
            write(outfile,g[i].Hardness:15:1);
            writeln(outfile,'???':18);
            writeln(outfile);
           end
    end;
  end;

{-----------------------------------------------------------------}
end. { unit }

{$R+}
unit PriQTool;
interface
  const MAXPQUEUESIZE= 25 ;
        MAX = 8 ;
  type  DataType=record
                     gride     :integer;
                     Hardness  :real;
                 end;
        HeapArrayType=array[1..MAXPQUEUESIZE] of DataType ;
        PriorityQueueType=record
                            HeapSize :integer;
                            HeapArray:HeapArrayType;
                          end;
  {must be called before the priority queue is first used }
  {also resets the priority queue so it is empty}
  procedure InitializePriorityQueue(var pQueue:PriorityQueueType);
  {error if called when it already has MAXPQUESIZE elements}
  procedure InsertPriorityQueue(var pQueue:PriorityQueueType;
                                                  info:DataType);
  {returns the element with the largest value}
  {error if no elements in the priority queue}
  function Maximum(pQueue:PriorityQueueType):integer;
  {removes and returns the element with the largest value}
  {error if no elements in the priority queue}
  function ExtractMaximum(var pQueue:PriorityQueueType):integer;
  function EmptyPriorityQueue(pQueue:PriorityQueueType):boolean;
  function SizePriorityQueue(pQueue:PriorityQueueType):integer;
implementation
  var i,j,K:integer;
{###############################################################}
  {error if the two binary trees that are children of the index do not
  satisfy the heap property}
  procedure Heapify(var pQueue:PriorityQueueType;i:integer);
    var L,R,largest:integer;
        temp:DataType;
    begin
        with pQueue do begin
          L:=2*i;
          R:=(2*i)+1;
          largest:=i;
          if (L <= HeapSize)  then begin
            if (HeapArray[L].Hardness > HeapArray[i].Hardness)
          then
             begin
              largest:=L;
             end ; {if}
          end;  {if}
          if (R<=HeapSize)  then begin
            if (HeapArray[R].Hardness>HeapArray[largest].
                Hardness) then
              begin
                largest:=R;
              end; {if}
          end; {if}
          if (largest <> i)then begin
            temp.gride   :=HeapArray[i].gride;
            temp.Hardness:=HeapArray[i].Hardness;
            HeapArray[i].gride   :=HeapArray[largest].gride;
          HeapArray[i].Hardness:=HeapArray[largest].Hardness;
          HeapArray[largest].gride    :=temp.gride;
          HeapArray[largest].Hardness:=temp.Hardness;
          Heapify(pQueue,largest);
        end;
      end; {with}
  end;
{removes and returns the element with largest value}
{error if no elements in the priority queue}
function HeapExtractMax(var PQueue:PriorityQueueType):integer;
  begin
      HeapExtractMax:=pQueue.HeapArray[1].gride;
      pQueue.HeapArray[1].gride := pQueue.HeapArray
                                    [pQueue.HeapSize].gride;
                                   pQueue.HeapArray[1].Hardness:=
                           pQueue.HeapArray  [pQueue.HeapSize].Hardness;
      pQueue.HeapSize:=pQueue.HeapSize-1;
      Heapify(pQueue,1);
  end;

{error if called when it already has MAXPQUEUESIZE elements}
procedure HeapInsert(var pQueue:PriorityQueueType;info:DataType);
  var parent:integer;
      check:boolean;
  begin
    with pQueue do begin
      HeapSize:=HeapSize+1;
      i:=HeapSize;
      parent:= (i div 2);
      check:=False;
      if parent=0 then begin
        check:=True;
      end else
      if HeapArray[parent].Hardness >= info.Hardness then begin
        check:=True;
      end;
      while ( ( i > 1 ) and not(check) ) do begin
        HeapArray[i].gride    :=HeapArray[parent].gride;
        HeapArray[i].Hardness:=HeapArray[parent].Hardness;
        i:=parent;
        parent:=(i div 2);
```

```
          if parent=0 then begin
            check:=True;
          end else
          if HeapArray[parent].Hardness >= info.Hardness then
         begin
            check:=True;
         end;
        end; {while}
        HeapArray[i].gride   :=info.gride;
        HeapArray[i].Hardness:=info.Hardness;
      end; {with}
    end;
{#################################################################}
  procedure InitializePriorityQueue;
    begin
      pQueue.HeapSize:=0;
    end;
  procedure InsertPriorityQueue;
    begin
      HeapInsert(pQueue,info);
    end;
  function Maximum;
    begin
      Maximum:=pQueue.HeapArray[1].gride;
    end;
  function ExtractMaximum;
    begin
      ExtractMaximum:=HeapExtractMax(pQueue);
    end;
  function EmptyPriorityQueue;
    begin
      EmptyPriorityQueue:=(pQueue.HeapSize=0);
    end;
  function SizePriorityQueue;
    begin
      SizePriorityQueue:=pQueue.HeapSize;
    end;
end. {unit_PriorityQueue}
```

LIST OF REFERENCES

1. Youngren, M.A., "Future Theater-Level Model, Draft," J-8,The Joint Staff, 24 April 1992.

2. Hartman, J.K., Parry, S.H., Caldwell, W.J., "High Resolution Combat Modeling," Naval Postgraduate School, Monterey, CA, 8 December 1992.

3. Schmidt, K.H., "Design Methodology for FTLM", Master's Thesis, Operations Research, Naval Postgraduate School, Monterey, CA, September 1993.

4. Youngren, M.A., "FTLM Architecture Specification, Draft," J-8, The Joint Staff, 24 April 1992.

5. Parry S.H., "STOCWAR-Some Design and Implementation Concepts", Naval Postgraduate School, Monterey, CA, 30 June 1992.

6. Parry S.H., "Future Theater Level Model Air Module design", Naval Postgraduate School, Monterey, CA, 21 November 1992.

7. Finney, R.L., Thomas, G.B., Calculus, Addison-Wesley Press, 1989.

8. Cormen, T.H., Leiserson, C.E., and Rivest, R.L., Introduction to Algorithms, M.I.T Press, 1990.

9. Kramer, J.S., "Simulation of Dynamic Tactical Route Selection With Application in the STAR Model", Master's Thesis, Operations Research, Naval Postgraduate School, Monterey, CA, March 1979.

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